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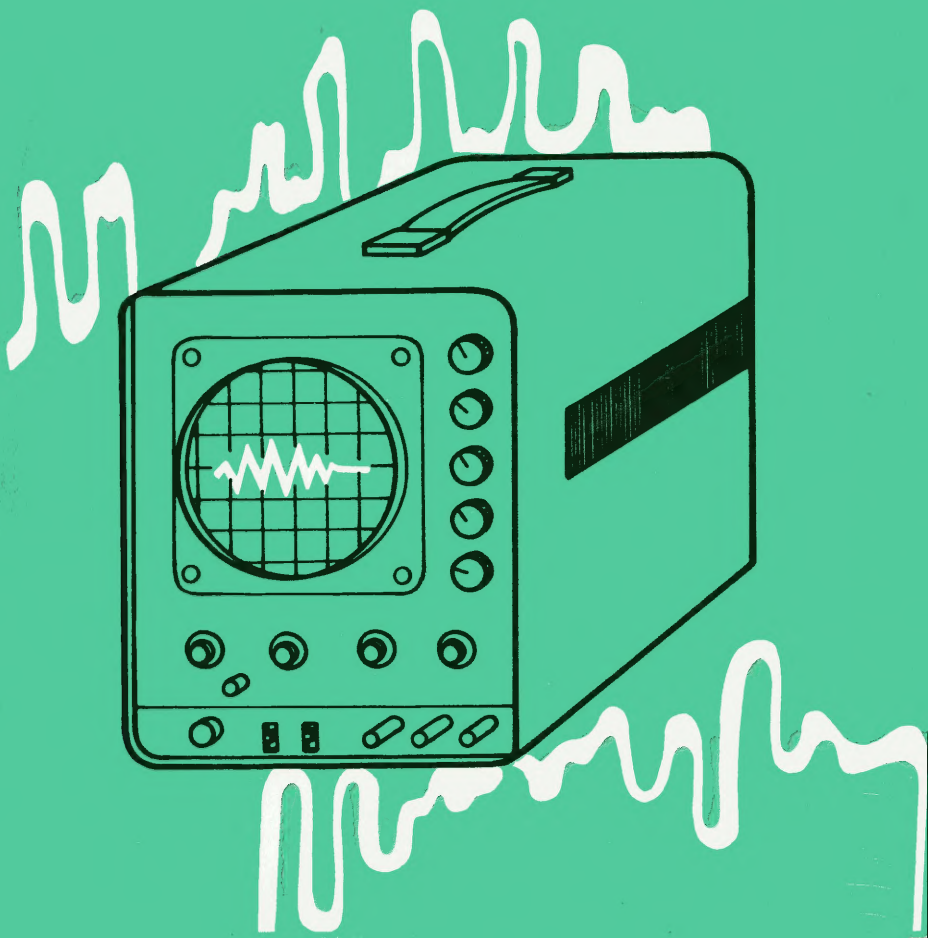
realistic guide to OSCILLOSCOPES



Realistic Guide to
OSCILLOSCOPES

by

Robert G. Middleton

radio shack
A TANDY CORPORATION COMPANY

FIRST EDITION

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PREFACE

The field of electronics has made spectacular progress within the past generation. Color television pictures from the moon are a landmark that will undoubtedly be surpassed by the generations yet to come. Though everyone makes use of electronics in daily activities, it is the amateur radio operator, the Citizens band enthusiast, the electronics hobbyist, the electronics technician, and the audiophile who know the fascination of this science. A satisfying sense of accomplishment is also known by those who achieve competency in using electronic test instruments in any of the specialized fields.

The oscilloscope is the most informative and interesting electronic test instrument. It is basically a voltmeter, but it does more than merely measure voltage. A waveform shows how a voltage rises and falls in time, and thereby provides a report on circuit action. It shows the various frequency components of color-tv waveforms, for example, with their time relations. Some waveforms indicate phase angles and others indicate impedance values. Nonlinear distortion, frequency distortion, and other faults in hi-fi systems are easily identified by scope tests. We will find that this unique instrument has important applications in amost every phase of electronics.

This book provides an introduction to the various types of oscilloscopes, and explains the functions of each. It shows how to use scopes in various basic applications. The fundamentals of waveform analysis are described and illustrated. Since different

types of scopes are required in various fields of electronics, these considerations are noted throughout the book. To get the most out of this descriptive material, the reader should supplement theory with practice and experiment with his own scope. In this way, better understanding is obtained and rapid progress can be made.

ROBERT G. MIDDLETON

WARNING

The cathode-ray tube in an oscilloscope operates at a high voltage, which can cause injury or death if accidentally contacted. Only experienced technicians should be permitted to operate an oscilloscope with its case removed. The power supply in an oscilloscope can be deceptive, since the heater and cathode of the crt are operated at 1000 or 2000 volts above ground.

Even when the oscilloscope is turned off, the filter capacitors may hold a deadly charge for a long time if the high-voltage bleeder resistor opens up. Always discharge filter capacitors before starting to troubleshoot scope circuitry. Remember that circuit defects can cause dangerously high voltages to appear at unexpected points in scope networks.

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CHAPTER 1

THE CATHODE-RAY TUBE

Electrons were formerly called cathode rays, because they emit from a hot cathode in a vacuum tube. A beam of electrons passing from cathode to anode in a vacuum tube is an electric current flow, just as free electrons passing through a copper wire is an electric current flow.

DISCOVERY OF CATHODE RAYS

It sometimes comes as a surprise to learn that the cathode-ray tube has been known in basic form since the discovery of the electron. The X-ray tube was invented in 1895, and scientists observed that there were mysterious blue streamers from the cathode. When an X-ray tube was highly evacuated, the glass walls produced a greenish fluorescence. Investigation by Joseph J. Thomson, an English physicist, proved that the fluorescence was caused by cathode rays. Thomson used cathode-ray tubes such as depicted in Fig. 1-1 to demonstrate that cathode rays were minute particles of negative electricty that travel at high speeds when attracted by a positive electrode. In Fig. 1-1, the cathode C emits electrons which are attracted by the metal diaphragm D (anode). This electrode is charged to approximately 30,000 volts, and electrons pass through the aperture at an extremely high velocity. Thomson placed a screen of zinc sulphide (P) at the far end of his cathode-ray

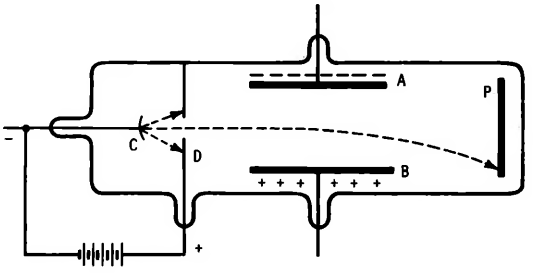


Fig. 1-1. First form of cathode-ray tube.

tube. In turn, the speeding electrons produced a bright spot on the fluorescent screen.

Thomson demonstrated the action of deflection plates A and B in Fig. 1-1, by applying various potentials to the plates. In this example, the lower plate is charged positively and the upper plate is charged negatively. In turn, the electrons in the beam are deflected downward, and the spot moves down on the fluorescent screen. This demonstration proved that electrons are negative particles. By taking into account the deflection voltage, the amount of screen deflection, and the length of the deflection plates, Thomson was able to calculate the various characteristics of an electron. He followed up with experiments in which the moving electrons were deflected by magnetic fields of known strengths. In turn, Thomson was able to show that an electron was 1860 times lighter than a hydrogen atom, and that it traveled at speeds of hundreds or thousands of miles per second when attracted by charged electrodes in cathode-ray tubes.

DEVELOPMENT OF CATHODE-RAY TUBES

Karl F. Braun, a German physicist, devised the next version of the cathode-ray tube, shown in Fig. 1-2. Note that a separate anode A was utilized. Approximately 50,000 volts were applied between the cathode and anode, and the emitted electrons speed toward diaphragm B. Like Thomson's cathode-ray tube, the diaphragm (which would be termed a grid today) had a central aperture through which the electron beam passed and proceeded to strike the fluorescent screen SC. Braun experimented with various kinds of fluorescent substances, and

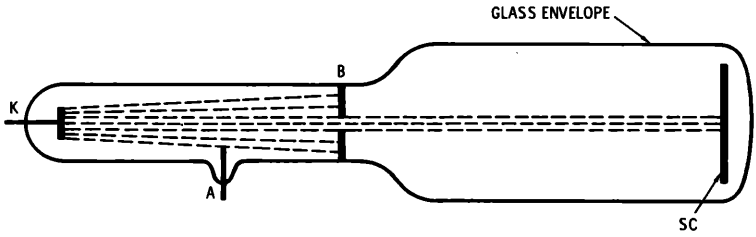


Fig. 1-2. Essentials of the Braun cathode-ray tube.

continued Thomson's investigation of beam deflection produced by electrostatic and electromagnetic fields.

It was not until 1921 that the cathode-ray tube assumed its present general design. The Johnson tube, named after J. B. Johnson and depicted in Fig. 1-3, employed a heated cathode, a simple beam-focusing arrangement, and two sets of deflection plates. A small amount of argon gas was introduced into

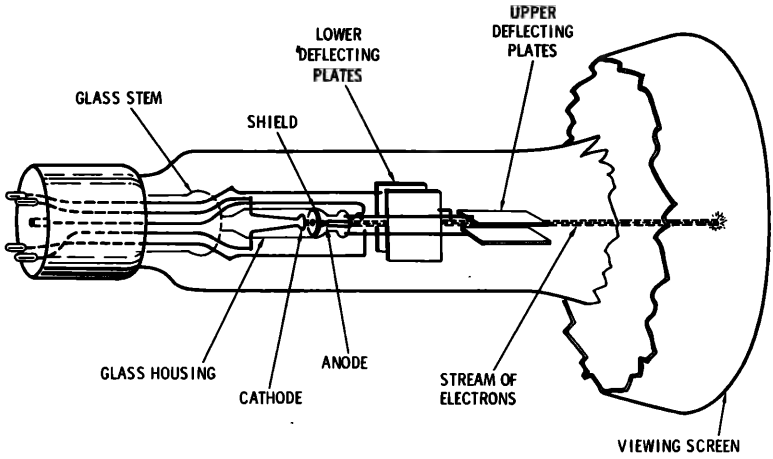


Fig. 1-3. Plan of the Johnson cathode-ray tube.

the crt to provide improved focusing action. That is, gas atoms become ionized or charged when struck by speeding electrons. The internal charge pattern provided a desirable electron-lens action. Because of the presence of these ions and because a heated cathode was utilized in the Johnson crt, the accelerating voltage was only 300 volts compared with the 50,000 volts required by the Braun crt. Many scientists have contributed

to modern cathode-ray tube design, and Fig. 1-4 depicts a modern type of high-vacuum crt construction. The *electron gun* comprises the cathode, grid, first anode, and second anode. This electron gun provides a source of electrons and focuses them to a sharply defined spot on the fluorescent screen. An aquadag (graphite) coating on the inner surface of the tube is utilized to collect the secondary electrons that are "splashed" out from the screen, and to thereby complete the electron-beam circuit.

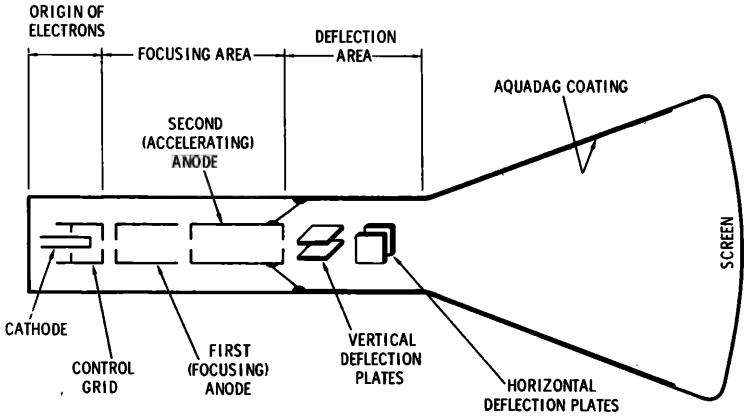


Fig. 1-4. Basic plan of the modern cathode-ray tube.

CATHODE-RAY TUBE OPERATION

Basic cathode-ray tube circuitry is shown in Fig. 1-5. Note that an accelerating potential of —1500 volts dc is applied to the cathode, and that the deflection plates are grounded. This mode of connection places the screen at ground potential, eliminating shock hazard to the operator. R3 is the intensity or brightness control. It is advanced to the point that a sufficiently bright pattern is produced on the crt screen. On the other hand, the brightness control must not be advanced excessively, or the screen phosphor is likely to be burned. R2 is the focus control. It is adjusted to obtain as sharply defined trace as possible. R4 and R5 are high-value resistors, such as 1 megohm. These resistors maintain the deflection plates at ground potential, while permitting a high-impedance input for signal voltages.

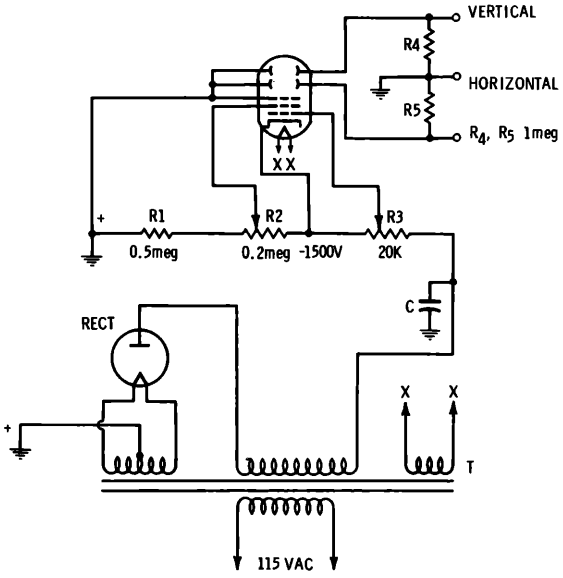


Fig. 1-5. Basic crt power-supply configuration.

If a 3AP1 crt is utilized in the arrangement of Fig. 1-5, the deflection sensitivity will be approximately 125 volts per inch. In other words, we will obtain a deflection of about an inch if 125 volts dc, or 125 volts peak-to-peak ac are applied to a pair of deflection plates. Inasmuch as a 117-volt sine wave is rated in rms value, it has a peak-to-peak value of 331 volts and will produce a deflection of more than 2.5 inches in this crt arrangement. The relations among rms, peak, and peak-to-peak values of a sine wave are shown in Fig. 1-6. Note that one volt dc will produce the same amount of beam deflection as one volt peak-to-peak ac. One of the important facts to note in the arrangement of Fig. 1-5 is that the crt has extremely high frequency response, and can be used to display signal frequencies up to several megahertz. An extremely high frequency response is very useful in many different types of applications; for example, television, microwave, and multichannel carrier.

One of the widely used applications for the basic crt arrangement in Fig. 1-5 is checking or monitoring the modulation of an amateur radio transmitter. Fig. 1-7 shows a test arrangement suitable for use with amateur transmitters of moderate power. The pickup loop has several turns, and is coupled

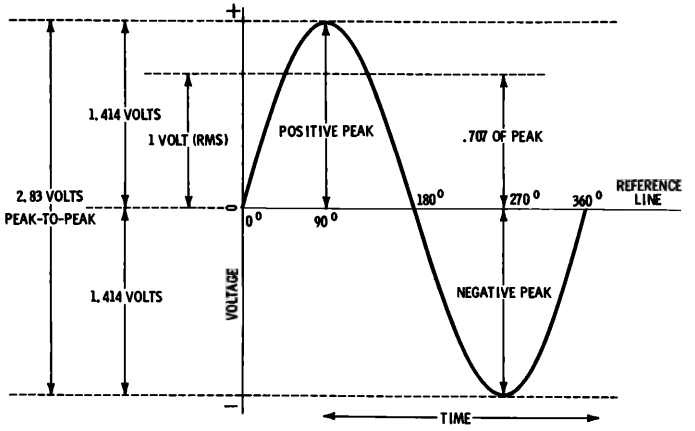


Fig. 1-6. Relations of rms, peak, and peak-to-peak voltages in a sine waveform.

to the tank at a distance that provides adequate vertical deflection on the crt screen. Beware of arcing if the loop is carelessly placed too near the tank. In case of inadequate vertical deflection, more turns may be used on the loop to avoid close coupling to the tank. C1 must have a voltage rating at least double the value of plate voltage applied to the modulator tube. The danger of breakdown in C1 is high-voltage damage to the test setup, as well as hazard to the operator. R1 is set to a position such that adequate horizontal deflection is obtained.

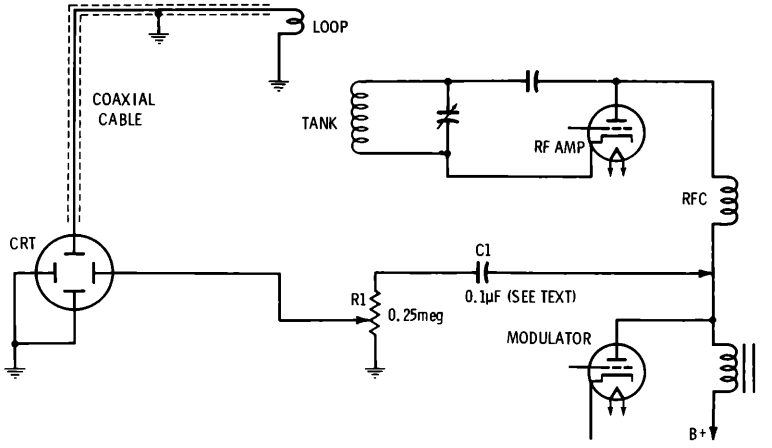


Fig. 1-7. Basic test setup for monitoring the modulation of an amateur phone transmitter.

When sine-wave modulation is used the test arrangement of Fig. 1-7 produces the screen patterns indicated in Fig. 1-8. These are called trapezoidal patterns and they are formed be-

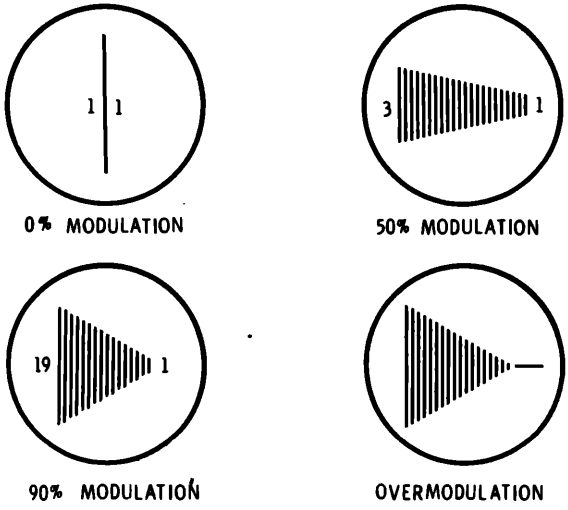
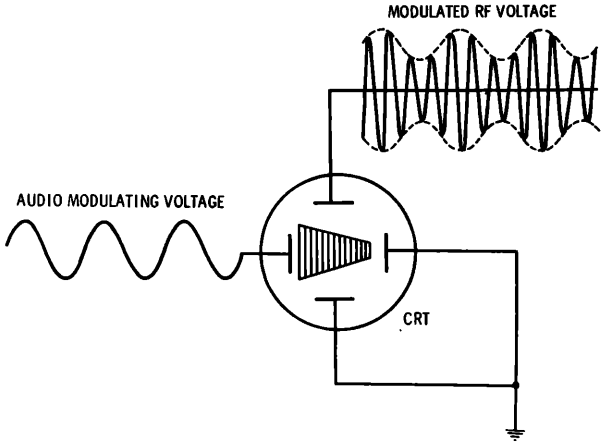


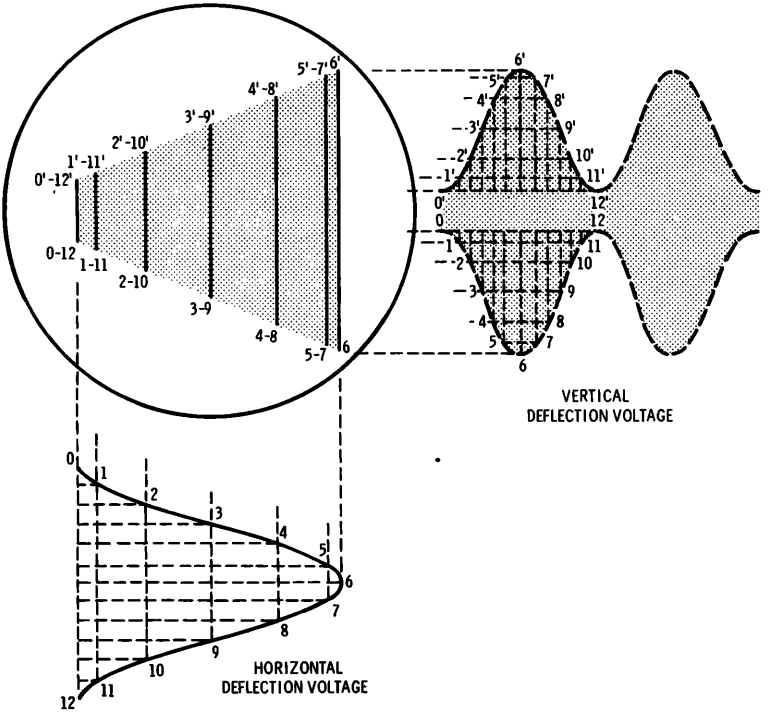
Fig. 1-8. Trapezoidal crt patterns produced by modulated waveforms with various percentages of modulation.

cause an audio modulating voltage is applied to the horizontal-deflection plates, and a modulated rf voltage is applied to the vertical-deflection plates of the crt. Fig. 1-9 depicts a modulating sine waveform, and its corresponding modulated rf waveform. In practice, trapezoidal waveforms (Fig. 1-8) may display foldover unless the pickup loop in Fig. 1-7 is rotated as required to apply a correctly phased signal voltage to the vertical-deflection plates. Note also that strong harmonics in the tank circuit can distort trapezoidal waveforms.

Another important application for the basic crt arrangement of Fig. 1-5 is the display of vectorgram patterns in color tv. Fig. 1-10A shows the basic plan of the test connections. The vertical-deflection plates of the crt are driven by the signal voltage at the red gun of the color picture tube, and the horizontal-deflection plates are driven from the blue gun. When the color-tv receiver is energized by a keyed rainbow signal, a typical vectorgram pattern (Fig. 1-10B) is displayed. A vectorgram pattern is produced by R — Y and B — Y signal

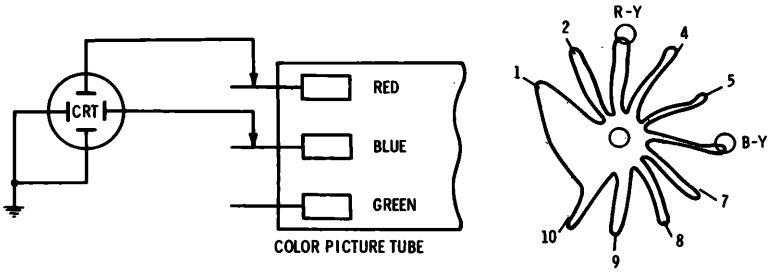


(A) Signal application to crt deflection plates.



(B) Point-by-point development of a trapezoidal waveform.

Fig. 1-9. Trapezoidal patterns are produced by modulated and modulating signal voltages.



(A) Basic plan of vectorscope operation. *(B) Typical vectorgram displayed on crt screen.*

Fig. 1-10. Oscilloscope applied in color-tv servicing as a vectorscope.

voltages, as shown in Fig. 1-11. These are pulsed sine waveforms, and they produce a special type of pattern on the crt screen.

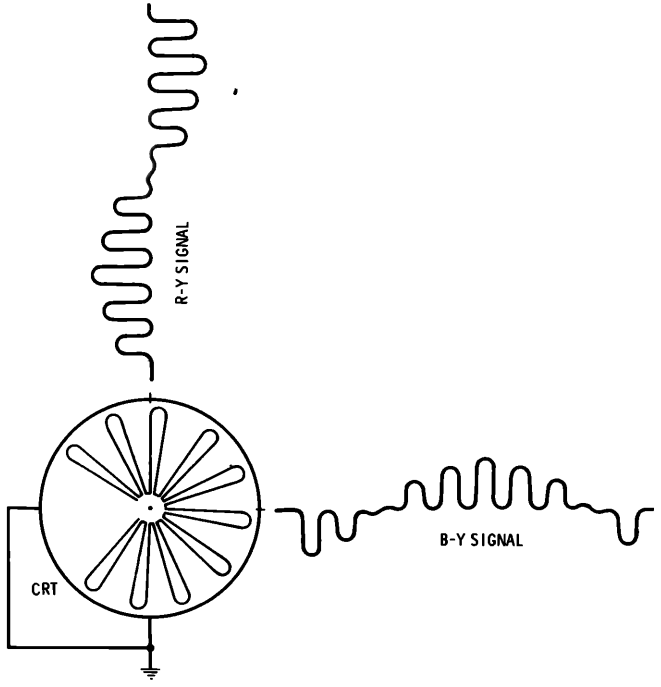


Fig. 1-11. Vectorgram produced by R — Y and B — Y signal voltages.

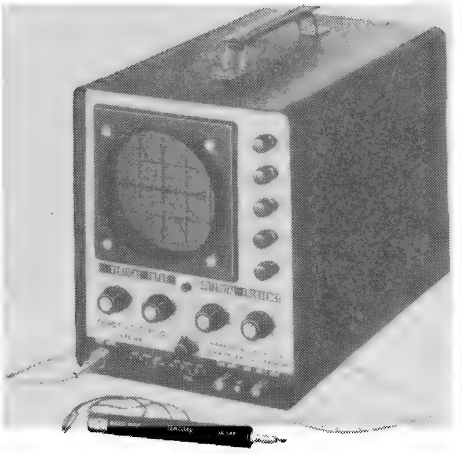
CHAPTER 2

OSCILLOSCOPE FUNDAMENTALS

Most modern service oscilloscopes are designed for application as either conventional oscilloscopes, or as vectorscopes. Fig. 2-1 illustrates a typical oscilloscope/vectorscope. An oscilloscope utilizes a rectangularly ruled graticule, as depicted in Fig. 2-2A, whereas a vectorscope utilizes a polar graticule, as depicted in Fig. 2-2B. In the example of Fig. 2-1, the graticule in front of the crt screen is provided with both types of ruling. We observe that the front panel has a number of operating controls. Among these are the intensity, focus, vertical-position, and horizontal-position controls. The other controls will be explained in the following topics.

FUNCTIONS OF THE BASIC OSCILLOSCOPE

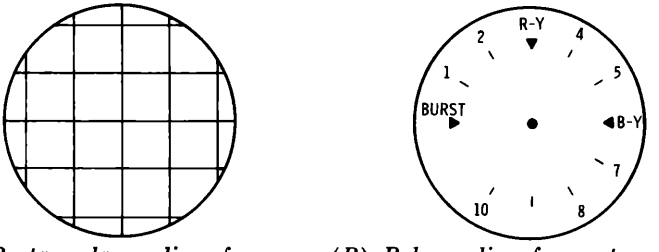
A simplified block diagram for a basic oscilloscope is shown in Fig. 2-3. The vertical amplifier steps up the input signal, in order to increase the deflection sensitivity of the crt. Thereby, tests in low-level circuits are enabled. It was noted previously that a crt has a typical sensitivity of 125 volts per inch. However, a vertical amplifier might provide a sensitivity of 0.03 volt per inch. This corresponds to a voltage gain of approximately 4000 times. Similarly, a horizontal amplifier is provided; the gain of this amplifier is usually less than that of the vertical amplifier in service scopes. For example, a horizontal amplifier may provide a deflection sensitivity of 1 volt per inch. This corresponds to a gain of 125 times.



Courtesy Sencore, Inc.

Fig. 2-1. Typical oscilloscope/vectorscope.

Next, we observe that a *time-base* section is utilized to drive the horizontal amplifier in the arrangement of Fig. 2-3. A time base is a sawtooth-waveform generator. Its function is to provide horizontal deflection of the electron beam in the crt, as depicted in Fig. 2-4A. Since a sawtooth waveform consists of a voltage that rises linearly with time, it causes the beam to move across the screen at a constant speed. In turn, the beam moves through each division on the graticule in a given time interval. For this reason, the sawtooth oscillator is called a linear time base. Next, if a sine-wave vertical-input signal is



(*A*) *Rectangular ruling for conventional oscilloscopes.* (*B*) *Polar ruling for vectorscopes.*

Fig. 2-2. Examples of graticules.

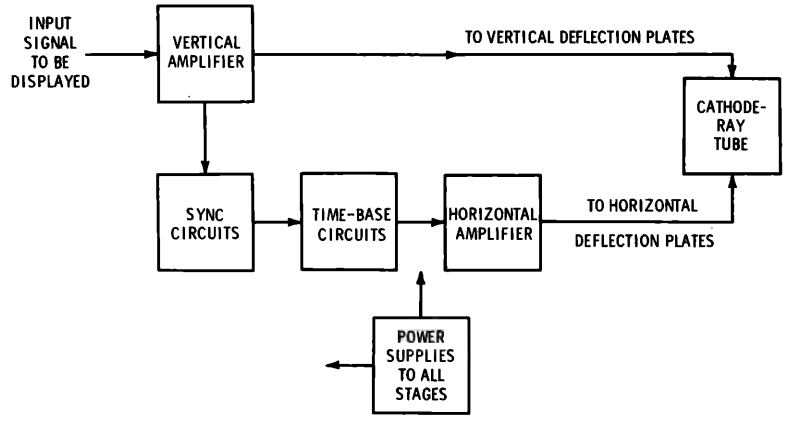
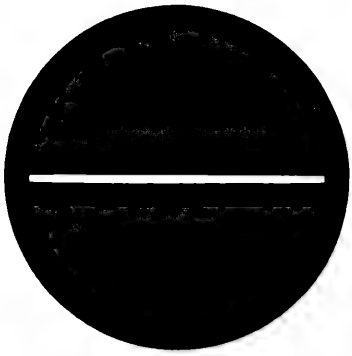


Fig. 2-3. Simplified block diagram of a basic oscilloscope.

applied to the vertical amplifier, a sine-wave pattern is displayed on the crt screen, as shown in Fig. 2-4B. The manner in which the pattern is developed is shown in Fig. 2-4C.

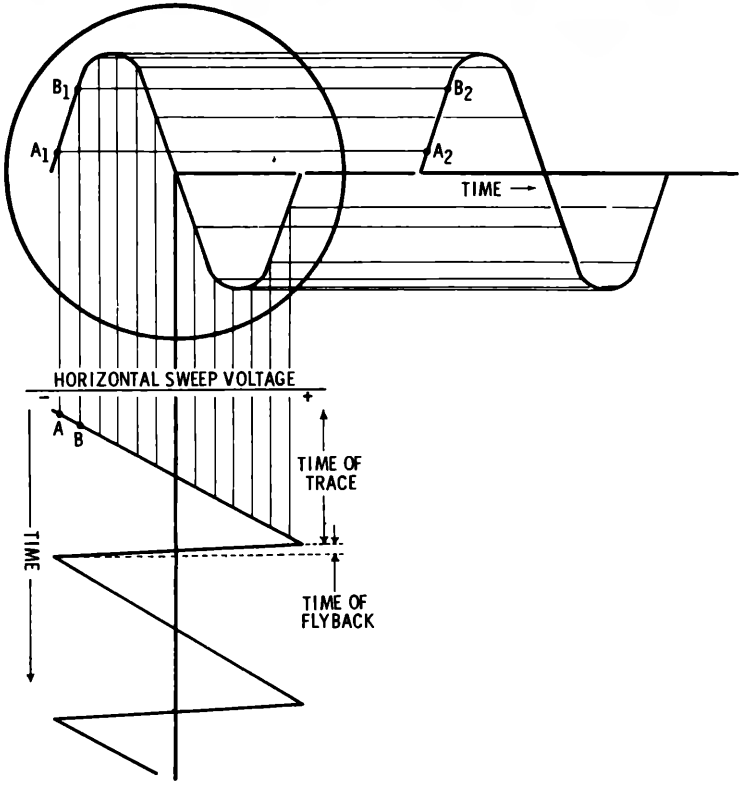
It is evident from Fig. 2-4C that one cycle of the sine-wave signal is displayed when the repetition rate of the sawtooth waveform is the same as the frequency of the sine wave. To keep this exact timing equal, the time-base oscillator must be synchronized (locked) to the vertical signal. Otherwise, the oscillator will drift off-frequency, and the pattern will "run" or blur on the crt screen. The *sync* section functions to keep the time-base oscillator in exact step with the frequency of the vertical-deflection signal. As seen in Fig. 2-3, a sample of the vertical signal is fed into the sync section, where it is processed for injection into the time-base section. To obtain proper sync action, the frequency of the sawtooth oscillator is adjusted so that it free-runs at a slightly lower rate than the vertical-signal frequency. In turn, injection of the sync signal causes the oscillator to start slightly earlier than it otherwise would, thereby maintaining a "lock-step" relation between the sine and sawtooth waveforms.

Modern service oscilloscopes employ vertical amplifiers that are essentially the same as video amplifiers in television receivers. However, the gain of a scope amplifier is comparatively high. Wideband scopes have a vertical-amplifier frequency response of 4 or 5 MHz. Some service-type scopes,



(*A*) *Horizontal beam deflection by time base.*

(*B*) *Sine waveform displayed with a linear time base.*



(*C*) *Development of the crt pattern.*

Fig. 2-4. Waveform display development.

used to troubleshoot black-and-white tv receivers only, have vertical amplifiers with a frequency response of 1 or 2 MHz. Economy service scopes may have a vertical-amplifier bandwidth of 100 or 200 kHz. Although the latter type can be applied to some extent in black-and-white tv service, its chief usefulness is in audio-frequency applications. The horizontal amplifier in most service scopes provides a frequency response of at least 100 kHz, and some modern designs have a horizontal-amplifier response up to 1 MHz. This greater bandwidth is an advantage when the horizontal amplifier is to be utilized in vectorscope applications.

Although the grouping of operating controls tends to vary from one oscilloscope to another, the layout depicted in Fig. 2-5 is typical. The crt control section includes intensity, focus, vertical-centering, and horizontal-centering controls. The sweep and sync control section includes step and continuous (coarse and fine) horizontal-frequency controls, and a sync-amplitude control. The vertical-amplifier section includes step and continuous vertical-gain controls. The horizontal-amplifier section includes a continuous horizontal-gain control, and may also have a step-gain control. In addition, various switches are commonly provided, as explained subsequently.

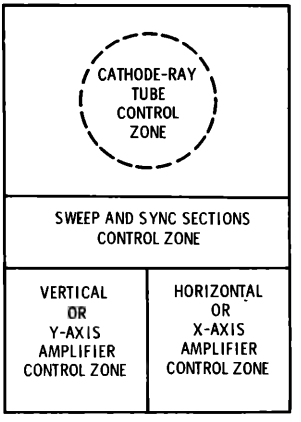
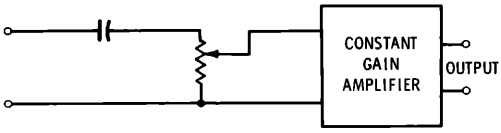

CATHODE-RAY TUBE CONTROL ZONE
SWEEP AND SYNC SECTIONS CONTROL ZONE
VERTICAL OR Y-AXIS AMPLIFIER CONTROL ZONE
HORIZONTAL OR X-AXIS AMPLIFIER CONTROL ZONE

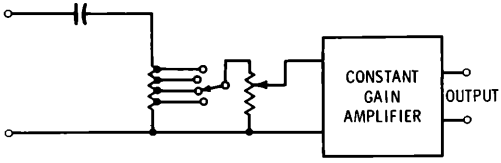
Fig. 2-5. Typical grouping of oscilloscope operating controls.

OSCILLOSCOPE CONTROL OPERATION

Basic circuitry for *continuous* (or vernier) control of vertical gain is shown in Fig. 2-6A. It is similar to a volume or con-



(*A*) *Principle of continuous control.*



(*B*) *Principle of step control.*

Fig. 2-6. Basic vertical-gain control circuitry.

trast control in a tv receiver. The principle of step control is depicted in Fig. 2-6B. This is a simplified representation. We will find that more elaborate circuitry is used in practice and that the continuous control is not directly connected to the step control. However, it is helpful to start with this representation, in order to clarify vertical-gain control operation. Service-type oscilloscopes always employ decade step controls. This means that each tap on the attenuator will reduce the amplitude of the applied signal to 1/10 of its previous value. To anticipate subsequent discussion, this feature is helpful when the technician proceeds to measure the amplitude of a waveform in peak-to-peak volts.

Although a step vertical-gain control produces large jumps in pattern height on the crt screen, the precise height that is desired is obtained by adjustment of the vernier control. That is, the vernier control "fills in" between the positions of the step attenuator. Fig. 2-7 illustrates how pattern height varies as the setting of the vernier vertical-gain control is advanced. In most applications, the control is set for approximately 2/3 of full-screen deflection. Similarly, the horizontal-gain control or horizontal attenuator is set for a pattern width of approximately 2/3 of full-screen in the majority of applications. Fig. 2-8 shows how a screen display varies in width as the horizontal-gain control is advanced. In particular applications, the horizontal gain may be set to expand part or most of the pat-

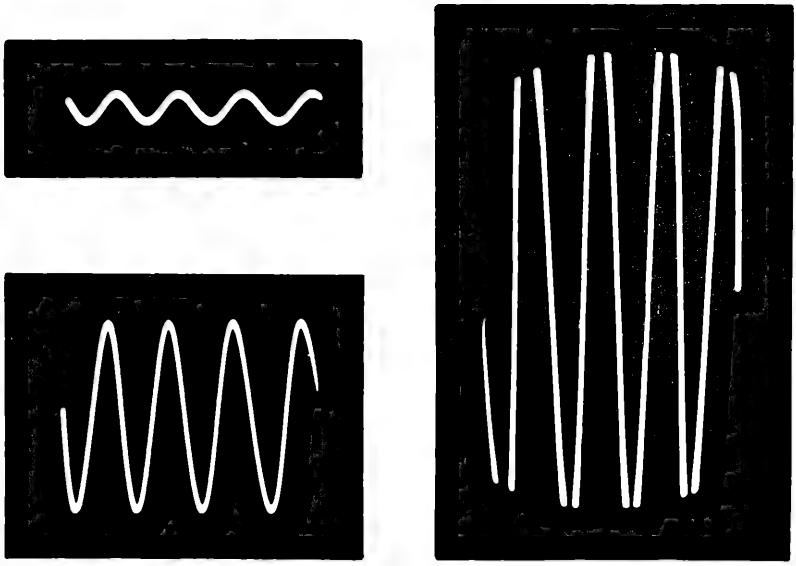


Fig. 2-7. Effect of vertical-gain control on pattern display.

tern off-screen in order to make some detail in the waveform more visible.

In most servicing applications, the horizontal-frequency control is set so that two cycles of the signal are displayed on the screen. That is, as the horizontal-frequency control is turned down, we first observe one cycle of the signal in the screen pattern, as exemplified in Fig. 2-4. Then, as the control is turned down somewhat more, the pattern "tears" and blurs. However, at a still lower setting, two cycles of the signal suddenly lock into the pattern, as shown in Fig. 2-9. Next, we may display three cycles of the signal, as seen in Fig. 2-8, or four cycles as in Fig. 2-7. In other words, as many cycles of the sig-

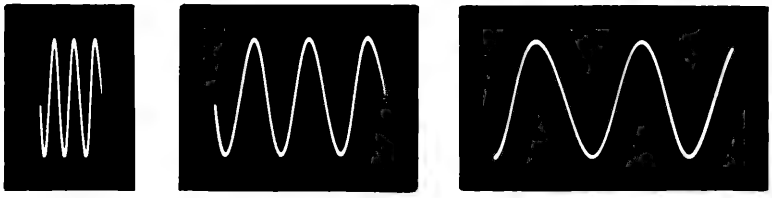


Fig. 2-8. Effect of horizontal-gain control on pattern display.

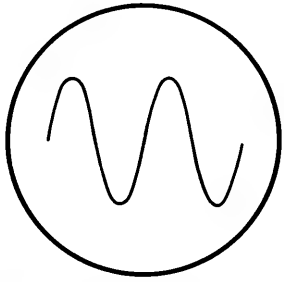


Fig. 2-9. Horizontal-deflection frequency set for a two-cycle display of the the vertical-input signal.

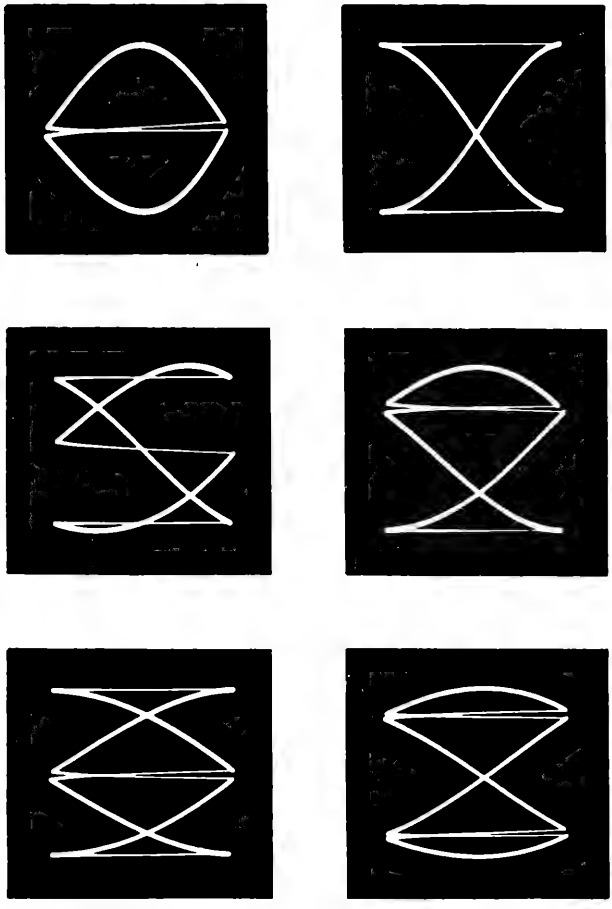


Fig. 2-10. Examples of pattern distortion caused by excessively high horizontal-deflection rates.

nal as may be desired can be displayed by suitable adjustment of the horizontal-frequency control.

If the horizontal-frequency control is set too high, so that the deflection frequency is greater than the vertical-signal frequency, we observe various distorted patterns, as exemplified in Fig. 2-10. This type of distortion should not be confused with the waveform distortion that results from setting the sync-amplitude control too high. Typical distortion patterns are shown in Fig. 2-11. Although the sync-amplitude control must be advanced sufficiently to lock the screen pattern tightly, excessively high settings must be avoided. If the oscilloscope controls are misadjusted in a way that results in distortion of the displayed waveform, the operator will falsely conclude that the circuit under test is operating incorrectly. In other words, the first consideration in practical applications is to obtain an undistorted display of the vertical-input signal.

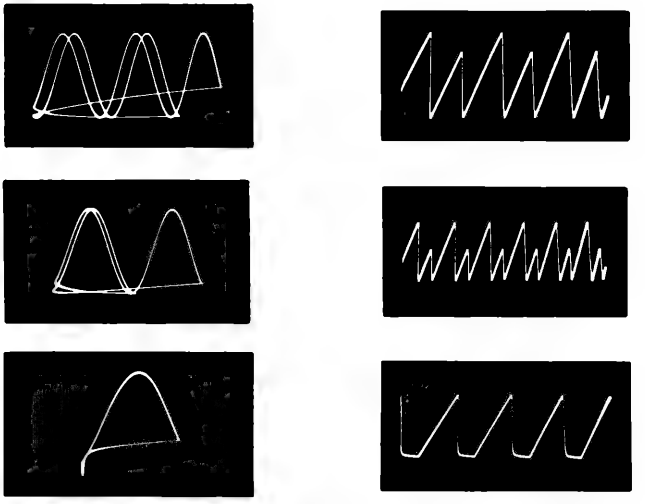


Fig. 2-11. Examples of pattern distortion caused by excessively high settings of the sync-amplitude control.

VERTICAL-AMPLIFIER CALIBRATION

Troubleshooting of tv-receiver circuits entails evaluation of waveshapes and also measurement of peak-to-peak voltages. Correct waveforms and their peak-to-peak voltages are speci-

fied in receiver service data. For example, four representative television waveforms are shown in Fig. 2-12, with their normal peak-to-peak voltages. To measure peak-to-peak voltages from screen waveform patterns, we must first calibrate the oscilloscope. This procedure consists in applying a known peak-to-peak voltage to the vertical-input terminals, and then adjusting the vertical-amplifier gain for a reference amount of deflection, such as 1 inch. For example, if we use a calibrating

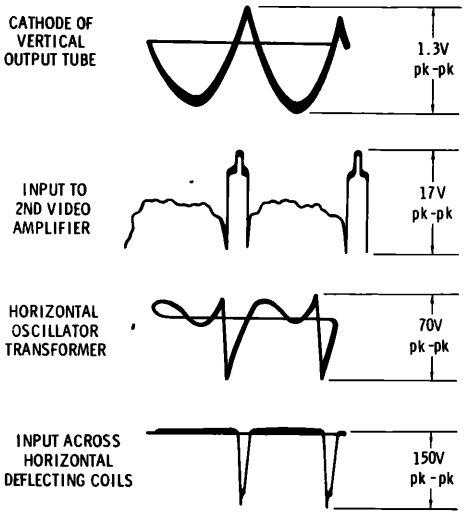


Fig. 2-12. Four complex waveforms observed in tv receiver circuits, with their peak-to-peak voltages.

voltage of 1 volt peak-to-peak and adjust the vertical gain for a deflection of 1 inch, the oscilloscope is then calibrated for a sensitivity of 1 volt peak-to-peak per inch. Next, if we apply a signal voltage to the vertical-input terminals and observe a vertical deflection of four inches, we know that the signal has an amplitude of 4 volts peak-to-peak.

Most service-type oscilloscopes provide a calibrating source voltage, such as 1 volt peak-to-peak. This facility may be brought out to a front-panel terminal, or it may be provided by a switch control. The switch is sometimes included as part of another control, or it may be individually mounted on the front panel. If a calibrating source voltage is not built into the scope, any convenient ac voltage source may be measured and

utilized to calibrate the vertical amplifier. For example, a heater-voltage source of 6.3 rms volts has a peak-to-peak value of approximately 17.8 volts. Most vacuum tube voltmeters and transistor voltmeters have direct-reading peak-to-peak voltage scales, that provide operating convenience. In any case, the value of a calibrating source voltage should be measured.

As a general procedure, the oscilloscope will be calibrated by setting the step attenuator to its $\times 1$ position and adjusting the vernier-gain control for a reference deflection interval. For example, if we employ a 1 volt peak-to-peak calibrating potential, and adjust the vernier-gain control for a deflection of one vertical division on the screen graticule, the scope is then calibrated for a sensitivity of 1 volt peak-to-peak per division. Next, if we do not change the setting of the vernier gain control, but move the step attenuator to its next position of $\times 10$, the scope is then calibrated automatically for a sensitivity of 10 volts per division. Then, if we move the step attenuator to its $\times 100$ position, the scope is automatically calibrated at 100 volts peak-to-peak per division.

DC OSCILLOSCOPES

In addition to being classified as wideband and narrowband, oscilloscopes are also classified as ac and dc types. An ac scope utilizes an ac-coupled vertical amplifier, whereas a dc scope utilizes a dc-coupled vertical amplifier. Note that a wideband ac scope has a typical frequency response from 60 Hz to 4 MHz. On the other hand, a wideband dc scope has a typical frequency response from zero hertz (dc) to 4 MHz. This is a useful feature in certain types of applications, such as testing high-fidelity audio amplifiers. A hi-fi amplifier generally has a low-frequency response down to 20 Hz, and many modern hi-fi amplifiers have full response down to zero hertz.

Basic responses of a dc scope to positive and negative dc input voltages are shown in Fig. 2-13. If an ac voltage is applied to the vertical-input terminals of a dc scope, the same screen pattern is obtained as if an ac scope were used. However, if an ac signal with a dc component is applied to the vertical-input terminals of a dc scope, the screen pattern is shifted up or down by an amount proportional to the value of the dc component. This form of screen display is exemplified in Fig. 2-14.

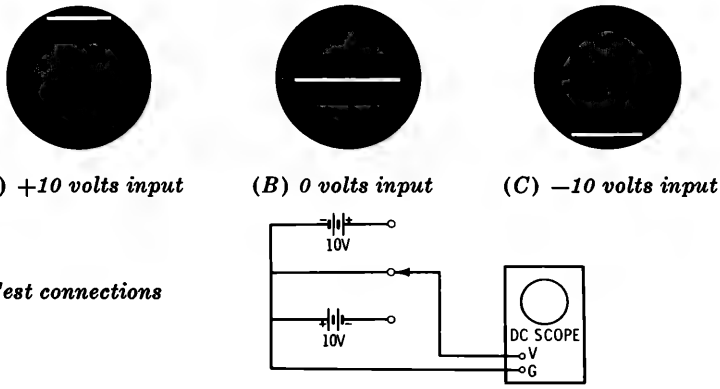


Fig. 2-13. Response of a dc scope to dc input voltages.

Note that the zero-volt level is established by the resting level of the horizontal trace when no input signal is applied to the scope. All dc scopes are provided with a switch, whereby a blocking capacitor can be connected in series with the vertical-input lead to change the scope over to ac response.

Dc scopes are very useful in certain kinds of applications. For example, the modulation depth (percentage of modulation) provided by a color-bar generator can be easily checked with a dc scope. Note in passing that this test requires the use of an auxiliary probe, called a demodulator probe, as explained in greater detail subsequently. The dc-coupled amplifiers used in service-type dc scopes are basically the same as

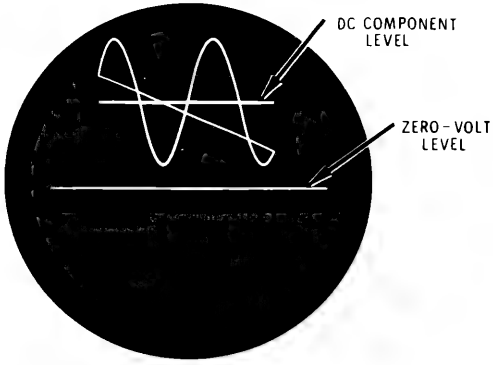


Fig. 2-14. Display of an ac signal with a dc component on the screen of a dc scope.

dc-coupled video amplifiers used in color-tv receivers. However, a vertical amplifier has much higher gain than a tv video amplifier. A few service scopes are designed with dc-coupled horizontal amplifiers, but the majority have ac-coupled horizontal amplifiers. A dc scope is generally more costly than an ac scope, because the former is designed with approximately twice as many tubes or transistors.

BASIC OSCILLOSCOPE PROBES

Probes are input coupling devices that are employed to apply a signal voltage from a circuit under test to the vertical-input terminals of a scope. Some probes have signal-processing functions, in addition to their coupling functions. The simplest form of "probe" is merely a pair of test leads. This fundamental arrangement is satisfactory for tests in low impedance circuits, such as power supplies, but is inadequate and will give misleading results if used to test in high-impedance circuits or tuned circuits such as intercarrier sound circuitry. The essential point with which we are concerned is the fact that a service scope has a very high vertical-input impedance, such as 1 megohm resistance shunted by 20 pF of capacitance. This high impedance is provided to avoid circuit-loading and detuning effects in ordinary receiver circuits. However, we encounter a problem when this vertical-input impedance is "brought to" the circuit under test with ordinary test leads.

In the first place, a pair of open test leads will pick up any stray fields that happen to be present at the service bench. Thus, 60-Hz hum fields are always present, due to the 117-volt wiring in the walls and at the bench. If a tv receiver is operating in the vicinity, 15,750-Hz stray field energy will also be present. When testing in high-impedance receiver circuits, stray-field pickup then combines with the correct signal waveform, thereby distorting the pattern display on the crt screen. For this reason, open test leads are seldom used with service-type scopes. Instead, the simplest form of "probe" supplied with a scope is a 3- or 4-foot length of coaxial cable. This *direct probe,* as it is commonly called, is chiefly useful for tests in low-impedance circuits.

A direct probe is unsuitable for tests in high-impedance receiver circuits because of its loading effect. That is, a direct

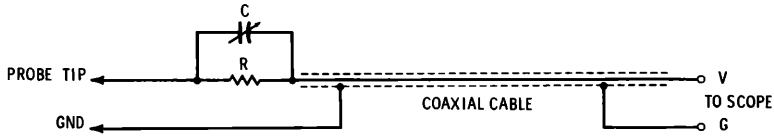
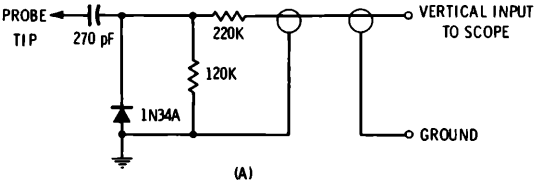


Fig. 2-15. Basic low-capacitance probe configuration.

cable has an input capacitance of 50 to 75 pF. In combination with a scope input capacitance of 20 pF, this means that a direct cable will shunt any circuit under test with a capacitance 70 to 95 pF. This amount of shunt capacitance will seriously disturb the action of high-impedance circuits, and will load many medium-impedance circuits objectionably. Moreover, 70 pF of shunt capacitance will seriously detune a 4.5-MHz ratio detector or intercarrier i-f stage. Therefore, a *low-capacitance probe* is standard equipment with the service scope, and is used in the great majority of receiver tests.

Fig. 2-15 shows the configuration for a basic low-capacitance probe. It is designed to match the scope with which it is to be used. For example, the input impedance to the coaxial cable, when connected to the scope, might be 1 megohm shunted by 80 pF. In turn, the low-capacitance probe would comprise a 9-megohm resistor R, and a 9-pF capacitor C. In practice, C is adjustable, so that it can be set for distortionless reproduction of complex waveforms. Once adjusted, the low-capacitance probe requires no further attention. This type of probe is designed to provide a signal attenuation to 1/10 of its original value. In turn, the probe provides an increase of 10 times the input impedance of a direct cable. We observe in Fig. 2-15 that the total input capacitance will be reduced to 1/10 of its original value. Thus, a low-capacitance probe involves a "trade-off" between signal attenuation and increased input impedance.

Another basic service-scope probe is termed a *demodulator probe,* detector probe, or traveling detector. As its name indicates, this kind of probe is a signal processor with detector action. Fig. 2-16 shows a circuit arrangement and operating characteristics of a typical demodulator probe. The essential feature of a demodulator probe is that it extends the effective high-frequency response of a scope to the vhf range. It does this by demodulating the input signal in the probe, and passing the modulation envelope to the vertical-input terminals



FREQUENCY RESPONSE CHARACTERISTICS:

RF CARRIER RANGE	500 kHz to 250 MHz
MODULATED-SIGNAL RANGE	30 to 5000 HERTZ
INPUT CAPACITANCE (APPROX.)	2.25 pF
EQUIVALENT INPUT RESISTANCE (APPROX.):	
AT 500 kHz	25,000 OHMS
1 MHz	23,000 OHMS
5 MHz	21,000 OHMS
10 MHz	18,000 OHMS
50 MHz	10,000 OHMS
100 MHz	5000 OHMS
150 MHz	4500 OHMS
200 MHz	2500 OHMS
MAXIMUM INPUT:	
AC VOLTAGE	28 PEAK VOLTS

Fig. 2-16. Configuration and characteristics of a typical demodulator probe.

of the scope. Since modulation envelopes of signals occurring in receivers have comparatively low frequencies, a service scope can respond satisfactorily.

One of the important applications for a demodulator probe is signal-tracing in the i-f amplifier of a tv receiver. Since the carrier frequency in this receiver section is 43 MHz, a service scope cannot respond to the i-f signal directly. However, when the i-f signal is processed by a demodulator probe as depicted in Fig. 2-17, the modulated waveform of the signal is displayed on the scope screen. A demodulator probe is seldom used for peak-to-peak voltage measurements because of its loading effect which tends to distort receiver waveforms. However the probe is very useful in applications where tests are made for presence or absence of high-frequency signals.

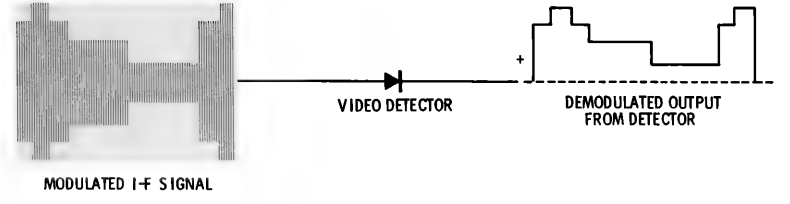


Fig. 2-17. Visualization of demodulator probe action.

CHAPTER 3

BASIC WAYS TO USE THE OSCILLOSCOPE

Oscilloscopes are used in television, radio, and high-fidelity servicing procedures. Industrial electronics, automotive service, and medicine are also important fields of application. The oscilloscope is an essential design tool, production test instrument, and incoming component tester. In television service, the oscilloscope is used as a waveform analyzer, frequency-response curve display device, signal tracer, component tester, and vectorscope. Thus, with the exception of the volt ohmmeter or transistor voltmeter, the oscilloscope is the most essential instrument in the modern service shop.

SCOPE WAVEFORM ANALYSIS

All complex waveforms can be built up from sine waves. For example, a *square wave* can be formed from sine waves as depicted in Fig. 3-1. Each sine wave has a harmonic relation to the fundamental and a certain amplitude. All harmonics of a square wave are in phase. Note that a square wave is composed of odd harmonics only. This is a basic characteristic of symmetrical waveforms. It is often helpful to analyze distorted square waveforms from the viewpoint of Fig. 3-1. For example, if an ideal square wave is processed through a low-pass filter, some of the higher harmonics are removed. In turn,

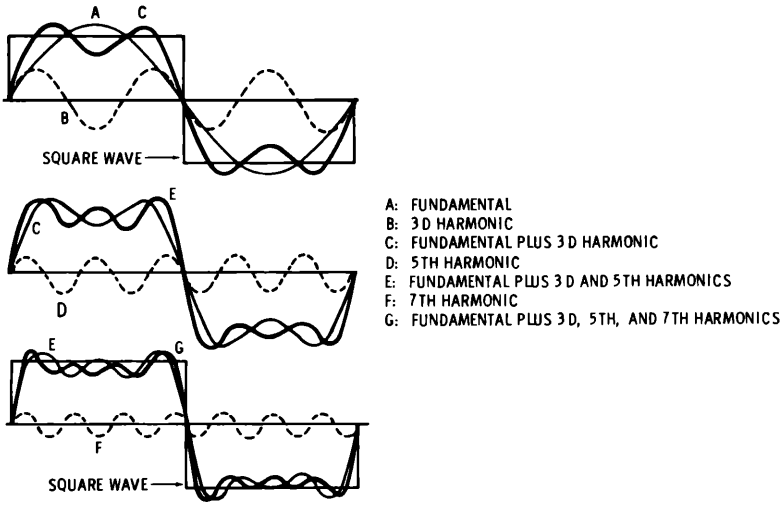
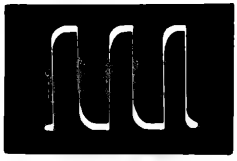


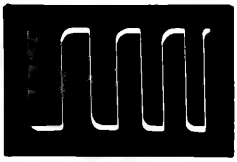
Fig. 3-1. Buildup of a square wave from sine waves.

the distorted waveform has rounded corners, as depicted in Fig. 3-2.

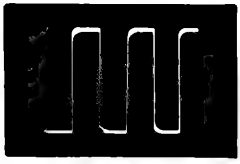
Corner-rounding can be regarded as a logical result of harmonic removal, because it takes a very large number of harmonics to create a reasonable facsimile of a square corner. Note that the diagonal corners are rounded in the example of Fig. 3-2. This is a result of phase shift, in addition to harmonic loss. If a square wave is passed through an ideal low-pass filter



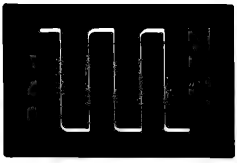
(A) 10 harmonics.



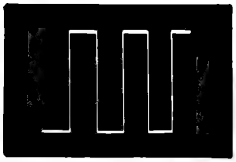
(B) 25 harmonics.



(C) 100 harmonics.



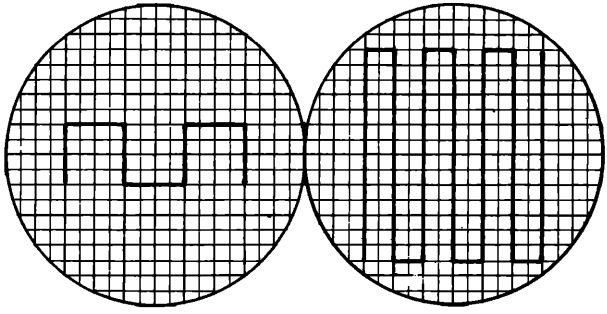
(D) 500 harmonics.



(E) Over 500 harmonics.

Fig. 3-2. Removal of higher harmonics from a square wave causes corner rounding.

that has zero phase shift, all four corners of the distorted output waveform are equally rounded. Note in passing that the aspect of a square wave depends to some extent on the setting of the scope gain control. For example, both of the displays in Fig. 3-3 are of the same square-wave input voltage. The only difference between the two displays is that the vertical-gain control is set higher in the second case.



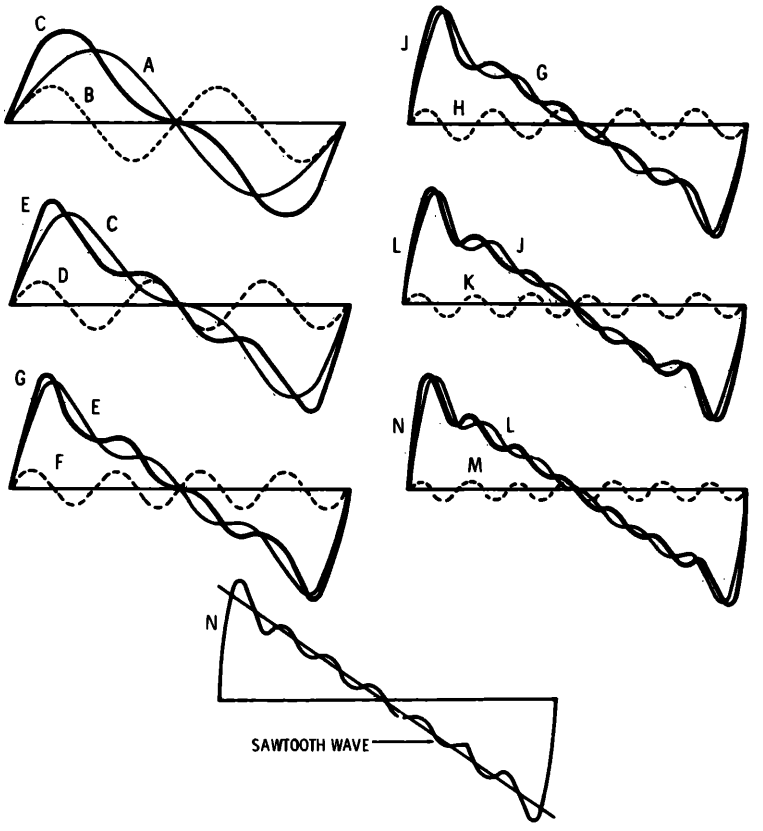
(*A*) *Square wave displayed in standard proportions.*

(*B*) *Same square wave expanded vertically and compressed horizontally.*

Fig. 3-3. Differences in waveform aspect, due to vertical-gain control setting.

Next, a *sawtooth waveform* can be built up from both even and odd harmonics, as shown in Fig. 3-4. We observe that all of the harmonics in a sawtooth waveform are in phase. A sawtooth contains even harmonics because it is not a true symmetrical waveform as the previous square wave was. That is, the first half cycle is different from the second half cycle in that the former is a mirror image of the latter. Most unsymmetrical waveforms have both even and odd harmonics. However, we will find that there are some unsymmetrical waveforms that are built up from even harmonics only. The output from a full-wave rectifier (Fig. 3-5) contains even harmonics only.

All ac waveforms have equal positive and negative areas above and below the zero-volt level (beam-resting level). For example, the *pulse waveform* depicted in Fig. 3-6 has equal positive and negative areas. On the other hand, any pulsating dc waveform or any ac waveform with a dc component has unequal positive and negative areas above and below the zero-volt level. These facts are shown in Fig. 3-7. Note that all three



LEGEND

A FUNDAMENTAL
B 2ND HARMONIC
C FUNDAMENTAL PLUS 2ND HARMONIC
D 3RD HARMONIC
E FUNDAMENTAL PLUS 2ND AND 3RD HARMONICS
F 4TH HARMONIC
G FUNDAMENTAL PLUS 2nd, 3rd AND 4th HARMONICS
H 5TH HARMONIC
J FUNDAMENTAL PLUS 2nd, 3rd, 4th AND 5th HARMONICS
K 6th HARMONIC
L FUNDAMENTAL PLUS 2nd, 3rd, 4th, 5th AND 6th HARMONICS
M 7th HARMONIC
N FUNDAMENTAL PLUS 2nd, 3rd, 4th, 5th, 6th AND 7th HARMONICS

Fig. 3-4. Sawtooth waveforms contain both even and odd harmonics.

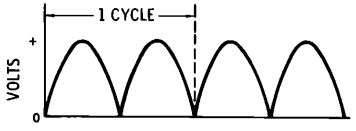


Fig. 3-5. Output waveform from a full-wave rectifier contains even harmonics only.

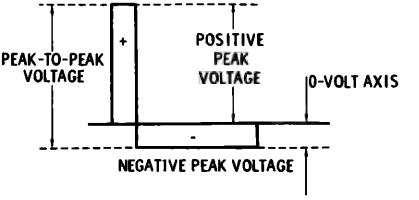


Fig. 3-6. A pulse has equal positive and negative areas above and below the zero-volt level.

of these waveforms will be displayed exactly the same on the screen of an ac scope. This is the result of rejection of the dc component. On the other hand, each of the waveforms is displayed at a different vertical level on the screen of a dc scope. As a result of this, the value of the dc component can be measured, as well as the peak-to-peak value of the ac component. As noted previously, the dc voltage and peak-to-peak voltage units of deflection are the same on a crt screen.

Another basic waveform that we often encounter in tv servicing procedures is the *exponential waveform.* The simplest

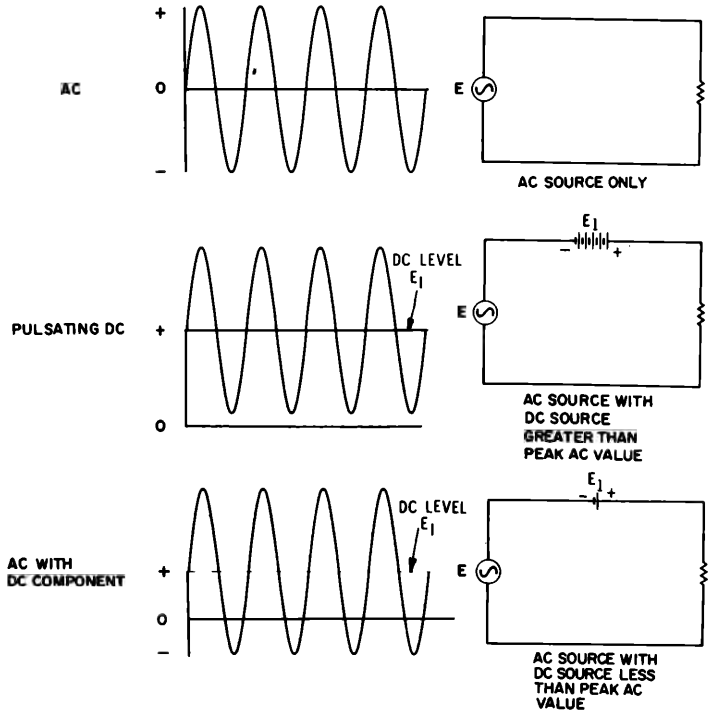
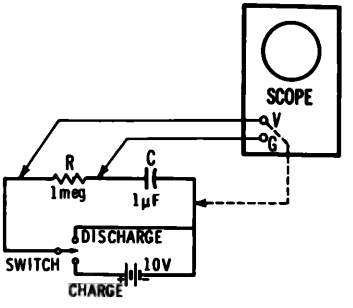
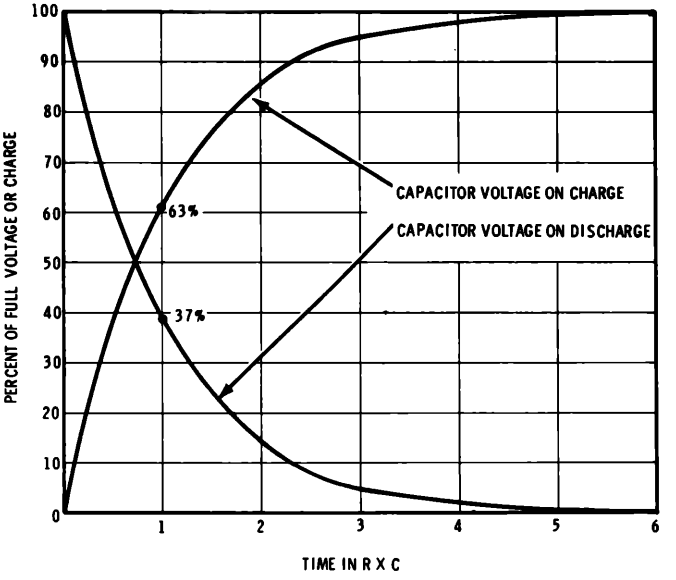


Fig. 3-7. Comparison of ac, pulsating dc, and ac with the dc component waveforms.

examples of exponential waveforms occur in the charge and discharge of a capacitor in an RC circuit, as depicted in Fig. 3-8A. Note that the discharge exponential is the same as the charge exponential "turned upside down." The *time constant* of an RC circuit is equal to the resistance in ohms multiplied by the capacitance in farads. This product denotes the time in seconds for the capacitor voltage to rise to 63% of its final potential, or the time in seconds for the capacitor voltage to



(*A*) *Circuit.*

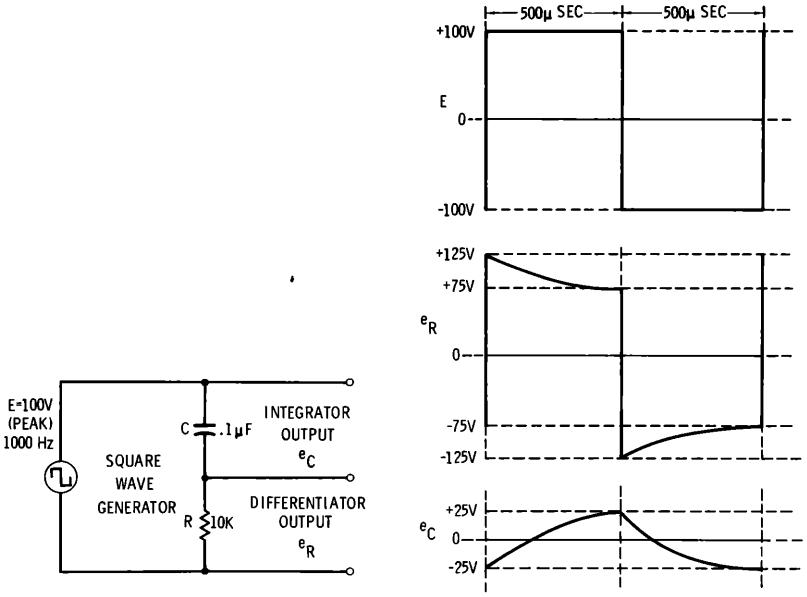


(*B*) *Curves.*

Fig. 3-8. Exponential waveforms in the basic RC circuit.

fall down to 37% of its maximum potential. These points are indicated on the exponential curves in Fig. 3-8B.

A series RC circuit *differentiates* and *integrates* a square wave, as shown in Fig. 3-9A. If the scope is connected across R, the configuration is called a differentiating circuit. Or, if the scope is connected across C, the configuration is called an integrating circuit. Note that the shapes of the differentiated and integrated waveforms are described by the exponential curves of Fig. 3-8B. A differentiating circuit is an elementary example of a high-pass filter. Similarly, an integrating circuit



(*A*) *Series RC circuit.* (*B*) *Waveforms.*

Fig. 3-9. Circuit actions of differentiating and integrating RC configurations.

is an elementary example of a low-pass filter. These circuit actions produce the difference in waveshapes that we observe across C and across R.

It is important to fully understand the reasons for the waveform voltages shown in Fig. 3-9B. At the instant that the square-wave generator applies +100 volts to the circuit, the capacitor voltage is −25 volts and the resistor voltage is +125 volts. The sum of the capacitor and resistor voltages is +100 volts—the same as the generator voltage. After 500 microsec-

onds, the charge on the capacitor has increased to +25 volts, and the voltage across the resistor has decreased to +75 volts. Also the sum of the capacitor and resistor voltages is still +100 volts—the same as the generator voltage. In fact, we will find that at any instant, the sum of the waveform voltages across C and R must be equal to the generator voltage.

FREQUENCY-RESPONSE CURVES

Another type of waveform that is of basic importance in television and radio servicing procedures is called the *frequency-response curve.* A typical frequency-response curve is illustrated in Fig. 3-10. It displays the signal output voltage over a band of frequencies. As explained in greater detail sub-

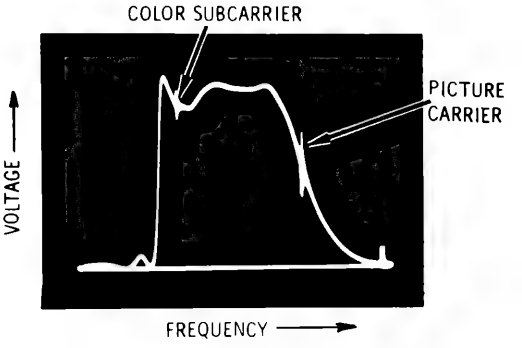
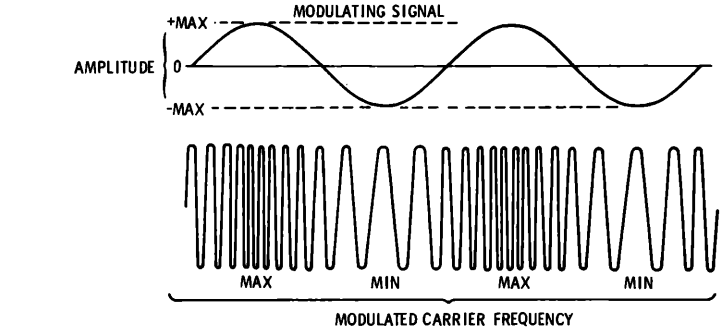


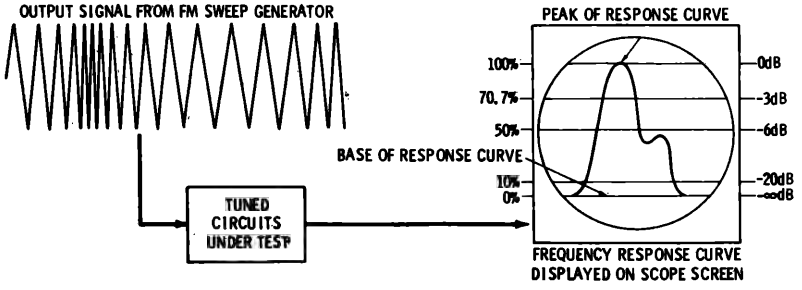
Fig. 3-10. Frequency-response curve for a color tv i-f amplifier.

sequently, frequencies of importance in servicing procedures are identified on the curve by means of *markers.* For example, picture-carrier and color-subcarrier markers are seen on the response curve in Fig. 3-10. A marker is produced by an i-f or rf generator, called a marker generator.

As depicted in Fig. 3-11B, a frequency-response curve is produced by applying a fm signal (also called a sweep-frequency signal) to the tuned circuits under test. For example, the sweep-frequency signal may be applied at the input of an i-f amplifier. In turn, the output from the detector is applied to the vertical-input terminals of a scope, and a frequency-response curve is displayed on the crt screen. The alignment procedure consists of adjusting the tuned circuits to obtain a



(A) Characteristics of a fm sweep signal.



(B) Plan of alignment setup.

Fig. 3-11. Development of a frequency-response curve.

response similar to that specified in the receiver service data. Evaluation of the scope pattern is made with the aid of frequency markers placed at key points on the curve. For example, the picture-carrier marker in Fig. 3-10 is specified halfway up the curve. With reference to Fig. 3-11B, this is the 50% or —6-dB level in the pattern. As another example, the sound-carrier marker is ordinarily specified 10% up (—20 dB down) on the i-f response curve.

The importance of correct frequency response is exemplified in Fig. 3-12 which shows five related frequency-response curves for a particular color-tv receiver. Since the output from the i-f amplifier is fed to the bandpass amplifier and to the Y amplifier, any distortion or incorrect frequency placement in the i-f curve will be passed along to the bandpass and the Y response curves. That is, the overall i-f and bandpass curve will be distorted, or out of frequency limits. Again, the output from the bandpass amplifier is fed to the chroma demodula-

tors, and any defects in the preceding frequency response will be passed along to the chroma-demodulator response curve. In turn, receiver performance is impaired.

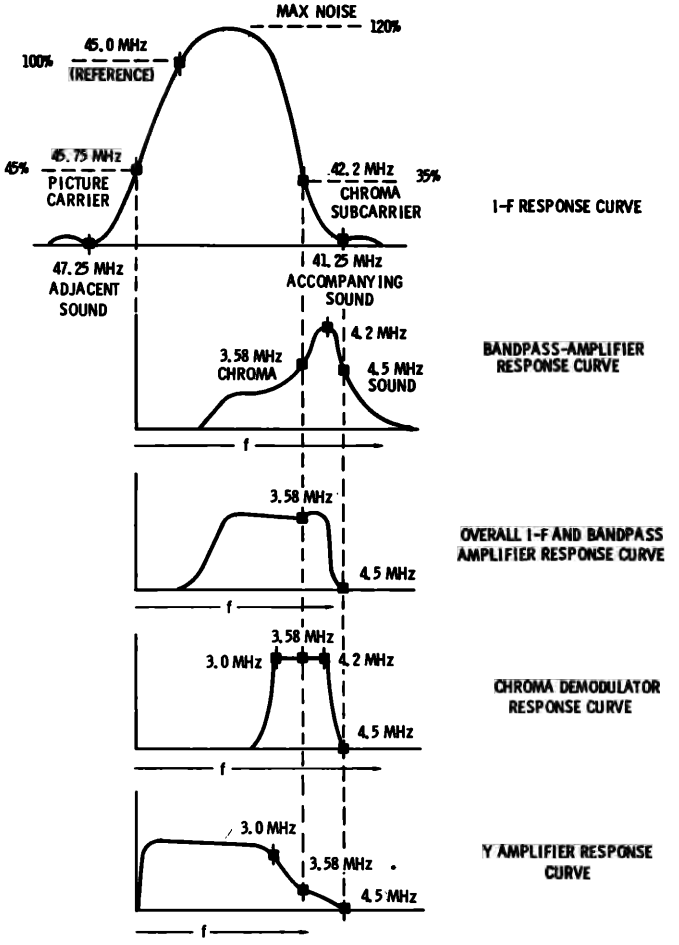


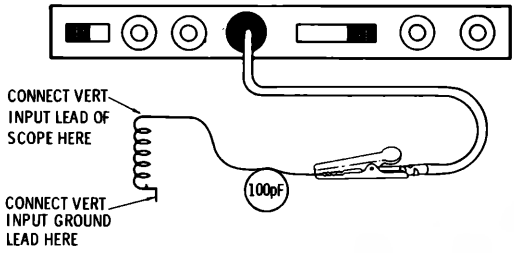
Fig. 3-12. Set of related frequency response curves for a typical tv receiver.

It is essential that the tuned circuits work together properly as a team in color-tv receiver operation. Therefore, comparatively elaborate sweep-alignment procedures are utilized in factories and service shops, for the purpose of checking overall frequency-response curves. The most widely used method is called *video sweep modulation* (vsm) alignment procedure.

This frequency-response test shows the overall response curve of a color-tv receiver from the antenna-input terminals to the chroma-demodulator output terminals.

COMPONENT TEST WAVEFORMS

Coils and transformers such as flyback transformers and deflection yokes may be tested by means of shock excitation from a pulse voltage. Modern service-type scopes often provide a pulse-output terminal on the front panel, which is convenient for making this type of test. As shown in Fig. 3-13A, a coil may be tested by connecting it in series with a 100-pF capacitor be-



(A) Pulse voltage obtained from scope.

(B) Display of a ringing waveform.

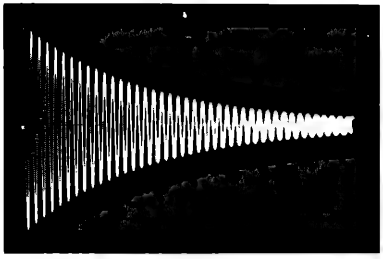
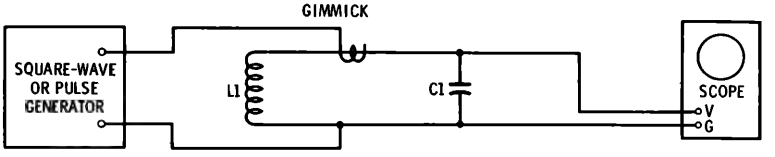


Fig. 3-13. Basic pulse testing arrangement.

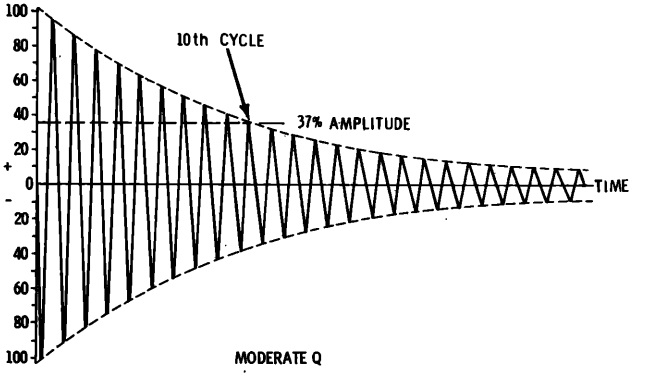
tween the pulse-voltage terminal and ground. In turn, the voltage across the coil is applied to the vertical-input terminals of the scope, and a waveform such as illustrated in Fig. 3-13B is displayed on the crt screen. This is called a *ringing waveform,* and its envelope is an exponential curve. The waveform may decay slowly or rapidly, depending upon the type of coil that is under test. In most cases, comparative tests

are made in which the observed waveform is compared with the waveform of a known good coil of the same type.

When a test-pulse voltage is not provided by a scope, a square-wave or pulse generator can be used, as depicted in Fig. 3-14A. The pulse voltage is coupled into the coil by means of a small capacitor, or with a few turns of wire around the coil lead (gimmick). If the coil normally operates with a capacitor in parallel, it is good practice to employ a similar capacitor in



(A) Typical test arrangement.

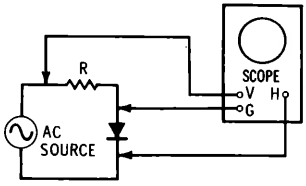


(B) Analysis of a waveform to measure the Q value.

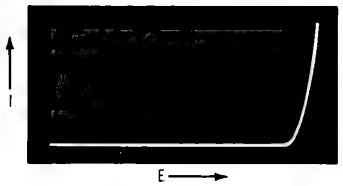
Fig. 3-14. Application of a square-wave or pulse generator in a ringing test.

the ringing test. It is interesting to note that the ringing waveform gives the approximate Q value of the coil, as exemplified in Fig. 3-14B. To measure the Q value, we observe the 37% level in the waveform, and count the number of peaks from the 100% point to the 37% point. This number multiplied by 3.14 gives the approximate Q value of the coil. In the present example, this Q value is seen to be 31.4, which is typical of various radio and television inductors.

Semiconductor diodes can be checked for their voltage-current characteristic as shown in Fig. 3-15A. This method is commonly used in factories for incoming inspection, because



(*A*) *Test setup for diodes.*



(*B*) *Typical voltage-current waveform.*

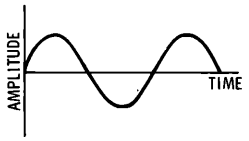
Fig. 3-15. Voltage-current display for a semiconductor diode.

the test is fast and accurate. A 6.3 volt 60-Hz sine-wave source is suitable, and resistor R is chosen with a sufficiently high value so that the maximum forward-current rating of the diode is not exceeded. In Fig. 3-15B vertical deflection is proportional to current flow, and horizontal deflection is proportional to the voltage across the diode. In turn, the voltage-current curve for the diode appears on the crt screen. When a calibrated scope is used, the corresponding voltage and current values can be measured at any point along the curve.

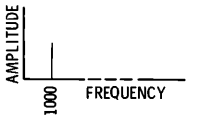
The basic test method depicted in Fig. 3-15A can be expanded for the purpose of checking the characteristics of transistors. In this application, a staircase generator is utilized in combination with a sine-wave source. This arrangement provides a display of the collector family, base family, or emitter family of characteristic curves for a transistor, depending on the arrangement of test connections. This type of test is necessarily involved, by comparison with simple diode tests, and details of transistor testing are not covered in this book.

MODULATED AND MIXED WAVEFORMS

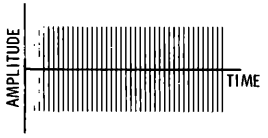
Modulated waveforms are sometimes confused with mixed waveforms. The distinction between these two basic types is shown in Fig. 3-16. If a 1-kHz sine wave is mixed with a 1-MHz sine wave, the resulting waveform contains these frequency components. On the other hand, if a 1-MHz sine wave is amplitude-modulated by a 1-kHz sine wave, the resulting waveform contains three frequency components—0.999 MHz, 1.000 MHz, and 1.001 MHz. In other words, amplitude modulation results in the production of sideband frequencies. These are new frequencies which were not present at the input of the modulator.



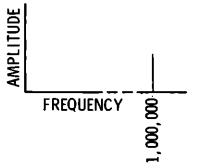
(*A*) *Sine wave.*



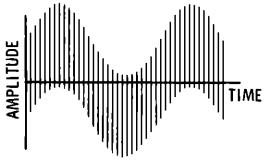
(*B*) *Bar graph of* (*A*).



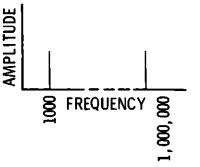
(*C*) *Higher frequency sine wave.*



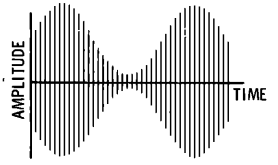
(*D*) *Bar graph of* (*B*).



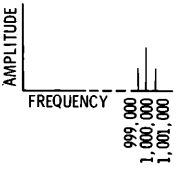
(*E*) *Mixing of* (*A*) *and* (*C*).



(*F*) *Bar graph of* (*E*).



(*G*) *Modulation of* (*C*) *by* (*A*).

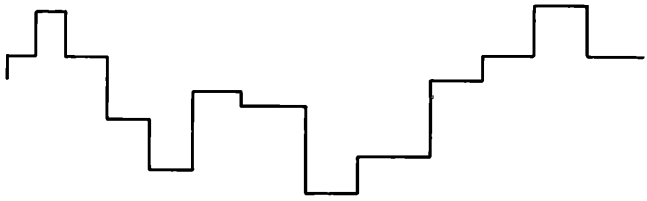


(*H*) *Bar graph of* (*G*).

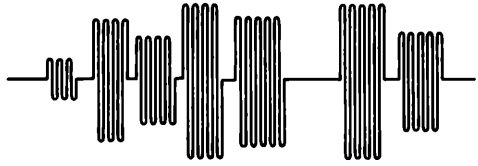
Fig. 3-16. Distinction between mixed and modulated waveforms.

The term "mixer," as commonly used in radio and tv receiver work, applies to circuits that may provide actual mixing action, or may provide modulating action. Thus, a mixer stage in a superheterodyne receiver is basically different from a mixer stage in a hi-fi audio system. The mixer in a superhet is a heterodyne mixer, whereas the mixer in an audio unit is not a signal processor. A heterodyne mixer is the same as an amplitude modulator, and is an example of a nonlinear mixer. On the other hand, an audio mixer is called a linear mixer. With reference to Fig. 3-11A, frequency modulation involves signal processing, and a frequency modulator is not a linear mixer.

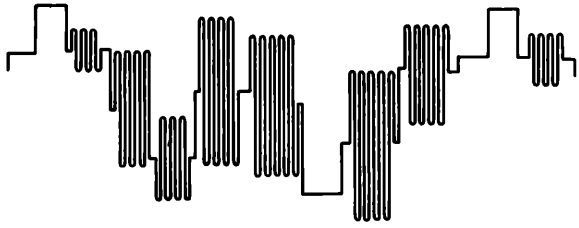
A NTSC color-bar signal is another important example of linear mixing of waveforms. Fig. 3-17 shows how a Y signal is



(*A*) *Y signal.*



(*B*) *Chroma signal.*



(*C*) *Saturated color-bar signal.*

Fig. 3-17. A NTSC color-bar signal is an example of linear mixing of waveforms.

combined with a chroma signal to form the complete color-bar signal. This action is provided in a NTSC color-bar generator. Subsequently, while the signal is passing through the receiver circuits, the Y and chroma signals are separated from the complete color-bar signal. The Y signal is fed to one channel, and the chroma signal is fed to another channel. This separation is accomplished in the first analysis by means of low-pass and high-pass filters.

Another important example of linear mixing of waveforms is encountered in stereo-multiplex circuitry. Fig. 3-18 shows how the sideband waveform of a modulated subcarrier is mixed with a sine-wave signal to form the familiar output signal from a stereo-multiplex generator. In the sequence depicted, the subcarrier is first amplitude modulated. This waveform consists of the subcarrier and a pair of sideband frequencies. Next, the subcarrier itself is suppressed; the result-

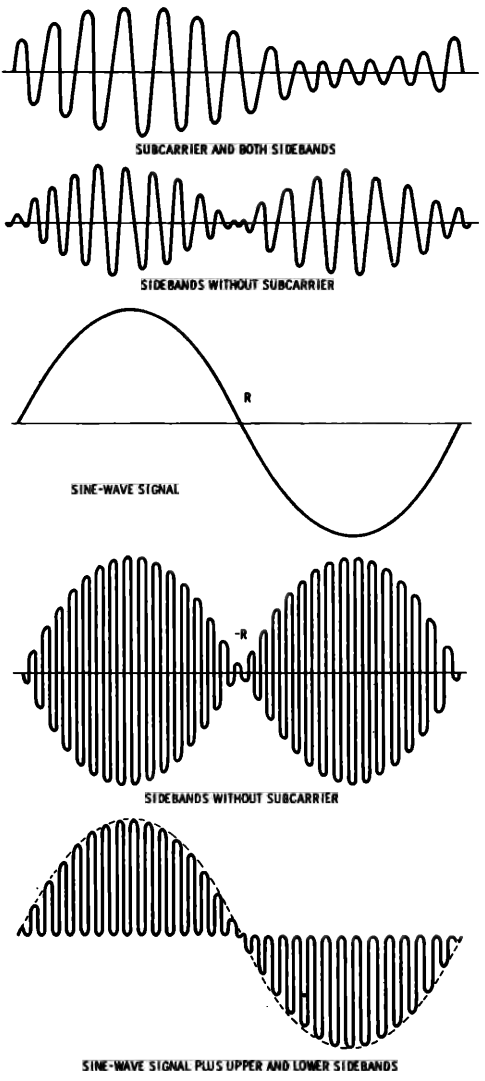


Fig. 3-18. Formation of a stereo-multiplex waveform.

ing waveform consists of a pair of sidebands without the subcarrier. Note that the suppression of the subcarrier results in a double-frequency modulation envelope. When this waveform is mixed with the modulating sine wave, a complete stereo-multiplex signal waveform is produced.

CHAPTER 4

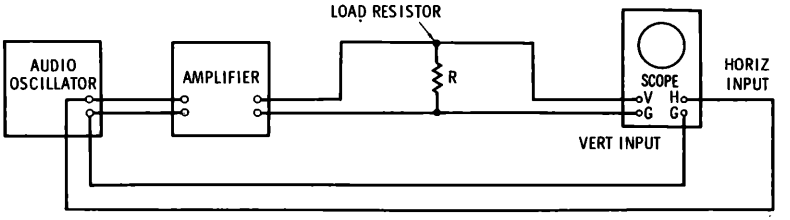
ELECTRONIC SERVICING APPLICATIONS

Oscilloscope applications in electronic servicing procedures can be classified into power-frequency, audio-frequency, video-frequency, intermediate-frequency, and also radio-frequency tests. Another classification is made into sine-wave and complex-wave tests. For example, square waves, pulses, test-pattern signals, and color-bar signals are complex waveforms. Further classification, however, is made into amplitude-modulated, frequency-modulated, and phase-modulated test signals.

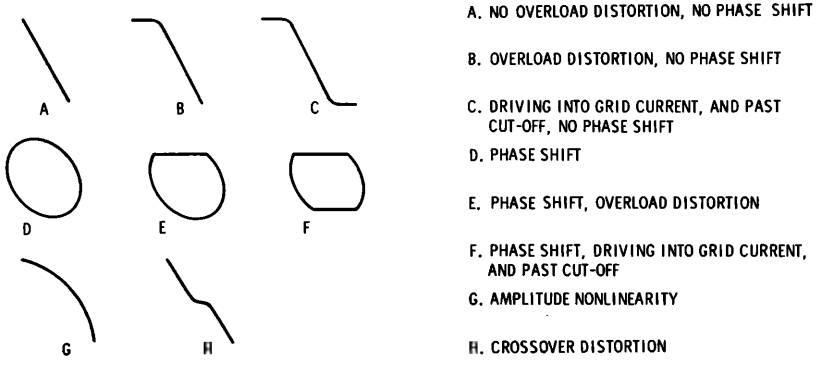
AUDIO SERVICING APPLICATIONS

Audio systems and units may develop various trouble symptoms, such as hum, no audible output, weak output, distortion, noise, and intermittent operation. When 60-Hz or 120-Hz hum is present in the sound output, a scope can be used to check the supply leads and signal paths to find where the hum voltage is entering and to trace back to its source. This is a typical power-frequency application.

Fig. 4-1 shows a basic audio-frequency application that utilizes an audio oscillator as a signal source and a scope as an indicator. A suitable power resistor is connected across the amplifier output terminals to provide a normal load. The audio-oscillator signal is applied to the input terminals of the



(A) Test connections.



(B) Pattern evaluations.

Fig. 4-1. Audio amplifier operating tests.

amplifier and to the horizontal-input terminals of the scope. The amplifier output signal is applied to the vertical-input terminals of the scope. In turn, a *Lissajous* pattern is displayed on the crt screen.

Next, let us examine the various screen patterns depicted in Fig. 4-1B. It is advisable to advance the output from the audio oscillator for maximum rated power output from the amplifier, because distortion usually shows up most prominently at maximum output. Preliminary tests are generally made at a frequency of 1 kHz. If the amplifier is in good operating condition, we will observe a straight diagonal line (A). On the other hand, in case overload is present, the line will appear bent at the end (B). Severe overload results in a line that is bent at both ends, indicated by (C).

It follows that a phase shift will show up as an elliptical pattern (D). Note in passing that a phase shift is not usually regarded as objectionable in an audio amplifier. However, it is not normal for an amplifier to develop appreciable phase shift at 1 kHz. By way of comparison, any amplifier will develop phase shift when operated at a test frequency near its high-frequency or low-frequency cutoff point. Phase shift with overload results in patterns similar to (E) or (F).

Amplitude nonlinearity results in curvature of a diagonal-line display (G). This is commonly caused by incorrect bias voltage on a tube or transistor. Crossover distortion shows up as shown in (H). This type of distortion is ordinarily caused by incorrect bias in a push-pull stage. An important point to keep in mind is that crossover distortion becomes more prominent at low operating levels, and might be overlooked at high operating levels. Finally, the frequency response of the amplifier in Fig. 4-1 can be checked by observing the pattern height over the rated frequency range, such as from 20 Hz to 20 kHz.

High-fidelity amplifiers may also be checked for square-wave response with the test arrangement shown in Fig. 4-2. A square-wave test is more demanding than a sine-wave test,

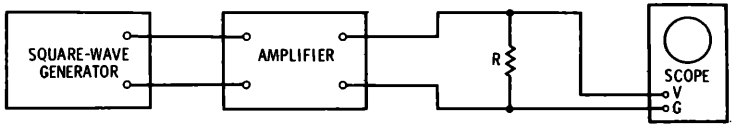
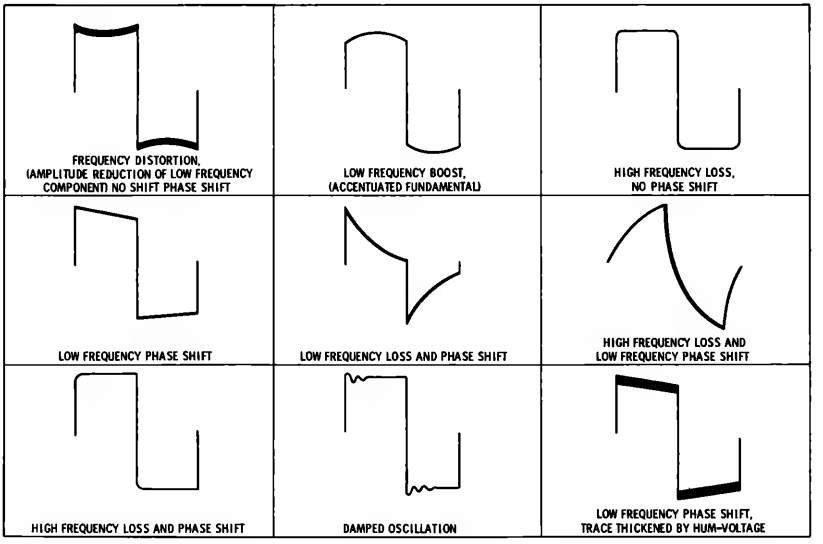


Fig. 4-2. Square-wave test of an audio amplifier.

because a square-wave signal includes transient response instead of steady-state response. Hi-fi amplifiers are usually rated for normal square-wave response over a specified range of repetition rates. Note that a square-wave pattern is not displayed as a Lissajous figure, and the scope is operated on horizontal sawtooth deflection. Basic square-wave distortions are depicted in Fig. 4-3. If the reproduced square wave curves down along its top, the fundamental frequency of the square wave is being attenuated. If the reproduced square wave curves up along its top, the fundamental frequency of the square wave is being boosted.

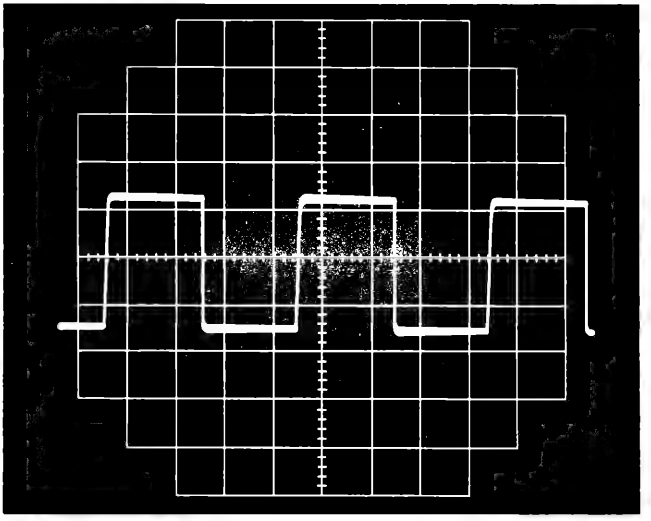
Fig. 4-4 exemplifies the specified square-wave response for a particular hi-fi amplifier at a repetition rate of 2 kHz. With


FREQUENCY DISTORTION, (AMPLITUDE REDUCTION OF LOW FREQUENCY COMPONENT) NO SHIFT PHASE SHIFT
LOW FREQUENCY BOOST, (ACCENTUATED FUNDAMENTAL)
HIGH FREQUENCY LOSS, NO PHASE SHIFT
LOW FREQUENCY PHASE SHIFT
LOW FREQUENCY LOSS AND PHASE SHIFT
HIGH FREQUENCY LOSS AND LOW FREQUENCY PHASE SHIFT
HIGH FREQUENCY LOSS AND PHASE SHIFT
DAMPED OSCILLATION
LOW FREQUENCY PHASE SHIFT, TRACE THICKENED BY HUM-VOLTAGE

Courtesy Precision Apparatus, Div. Dynascan Corp.

Fig. 4-3. Basic square-wave distortion.

reference to Fig. 4-3, excessive thickening of the top and bottom intervals of a reproduced square wave can be caused by hum voltage; a high noise level is another possible cause.



Courtesy General Electric Co.

Fig. 4-4. Specified 2-kHz square-wave response for a typical hi-fi amplifier.

Rounded corners indicate attenuation of the higher harmonics in a square wave. Tilt along the top and bottom indicates low-frequency phase shift. In many cases, both frequency discrimination and phase shift are present in a distorted square wave. Transient oscillation, or ringing, can be caused by a defective negative-feedback loop.

In a stereo amplifier system, a multiplex unit is utilized to separate left-channel signals from right-channel signals. One of the basic tests concerns the number of dB separation that is accomplished. A stereo signal generator is used to drive the system, as shown in Fig. 4-5. A scope can be used as an indi-

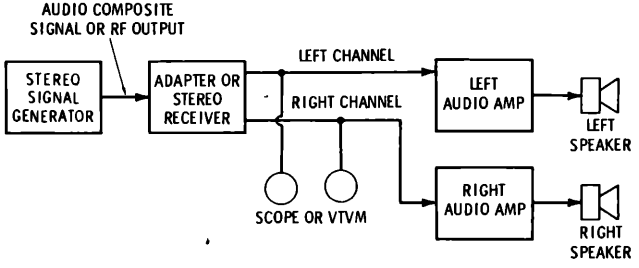
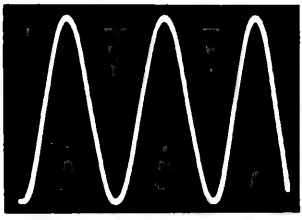
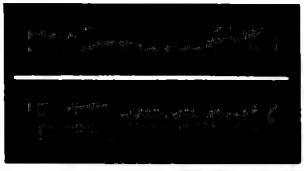


Fig. 4-5. Setup for separation test of a stereo system.

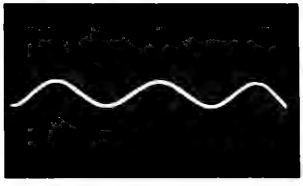
cator and connected at the left and right output terminals in turn. The result of a typical separation test is illustrated in Fig. 4-6. A high-quality multiplex unit will provide approxi-



(*A*) *Right-channel output.*



(*B*) *Ideal left-channel output.*



(*C*) *Normal left-channel output.*

Fig. 4-6. Typical separation patterns.

mately 30 dB of separation. This corresponds to a voltage ratio of more than 30 between left and right channels when testing with a left signal or a right signal. A separation of 10 dB is considered to be marginal. In the example of Fig. 4-6, the voltage ratio of the two sine waveforms is 7 to 1, which corresponds to a separation of approximately 17 dB.

LISSAJOUS PATTERN FUNDAMENTALS

We will find that there are test procedures in hi-fi servicing in which Lissajous patterns are displayed. Therefore, it is helpful to note the basic types of Lissajous patterns. First, we observe that a circular Lissajous pattern is formed when sine waves of the same frequency, but 90° out of phase, are applied to the vertical- and horizontal-deflection plates in the crt. Fig. 4-7 shows how this pattern is developed. Note that both sine waves have the same amplitude. If unequal sine-wave volt-

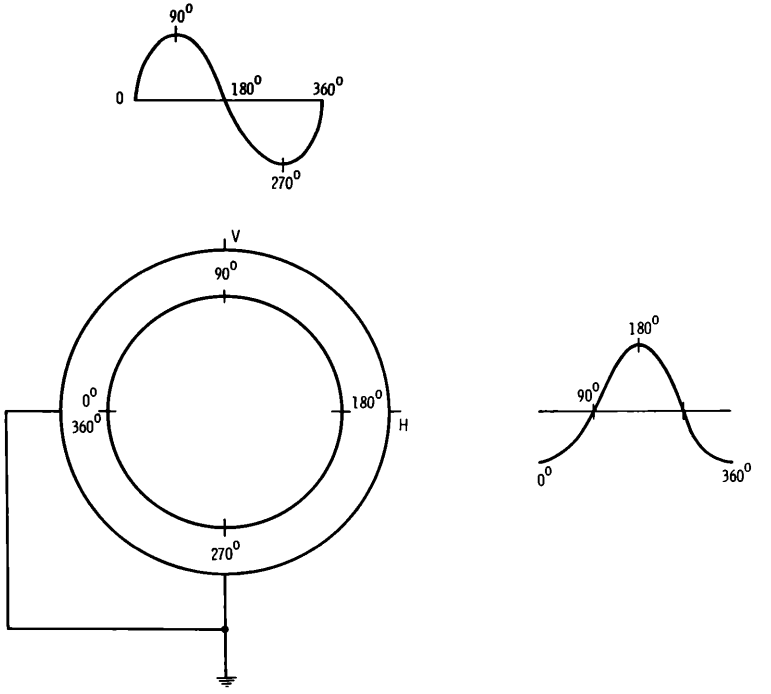
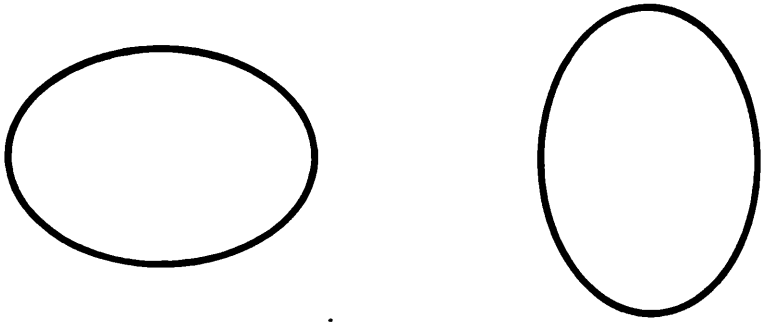


Fig. 4-7. Development of a circular Lissajous pattern.

ages are utilized, a vertical or horizontal ellipse is formed, as depicted in Fig. 4-8. As in the case of the circular pattern, these ellipses correspond to sine-wave signals that are 90° out of phase.



(*A*) *Horizontal signal greater than vertical signal.* (*B*) *Vertical signal greater than horizontal signal.*

Fig. 4-8. Elliptical Lissajous patterns.

When Lissajous patterns are produced by sine waves that are more or less than 90° out of phase, inclined ellipses are displayed, as shown in Fig. 4-9. Note that an inclined-line pattern is a special case of an ellipse that results from sine waves which are in phase or 180° out of phase. Phase variations from 180° to 360° produce the same series of Lissajous patterns in a reverse sequence. A Lissajous pattern is often employed to measure the phase difference between two sine-wave voltages. The procedure is seen in Fig. 4-10. First, the pattern is centered on the crt screen. Then, the deflection intervals C and D are measured. In turn, the ratio of C to D gives the sine of the phase angle that we wish to find. Accordingly, we look up the C/D value in a table of sines to find the phase difference between the two sine-wave voltages.

When Lissajous patterns are used to check the calibration of an audio oscillator, for example, we apply sine waves of

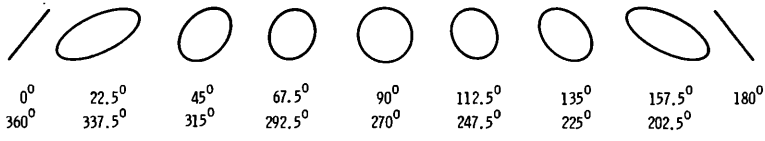


Fig. 4-9. Lissajous patterns formed by signals with various phase differences.

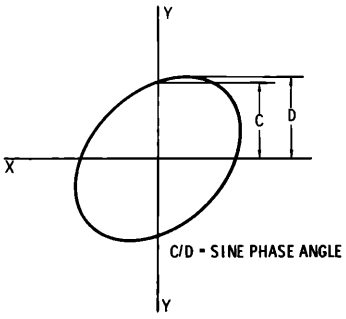


Fig. 4-10. Measurement of the phase difference between two sine-wave voltages with a Lissajous pattern.

different frequencies to the vertical- and horizontal-deflection plates in the crt. In shop calibration procedures, the 60-Hz power line voltage is often applied to the vertical-deflection plates, and the output from an amplifier is applied to the horizontal-deflection plates in the crt. (See Fig. 4-11.) When the

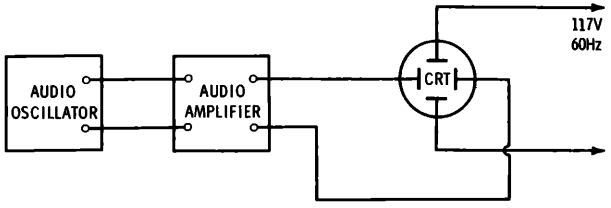


Fig. 4-11. Audio oscillator calibration arrangement.

audio oscillator is set exactly at 60 Hz, we observe a circular, elliptical, or diagonal-line pattern, as shown in Fig. 4-10. Unless the audio-oscillator frequency is set very carefully, the pattern will usually change slowly back-and-forth through the phases noted in the diagram. That is, a slight frequency difference corresponds to a slowly varying phase change. The audio oscillator is adjusted to make the Lissajous pattern "stand still," and the dial calibration is noted.

Next, the audio oscillator is tuned to 120 Hz, and we observe the bow-tie or "lazy-8" Lissajous pattern depicted in Fig. 4-12. As before, the bow-tie pattern changes with any phase variation between the two sine-wave voltages. Note that the reference in-phase bow-tie pattern is tangent along two points on the horizontal line and one point on the vertical line. The technician utilizes this basic tangential relationship to determine the frequency ratio in any Lissajous pattern. For ex-

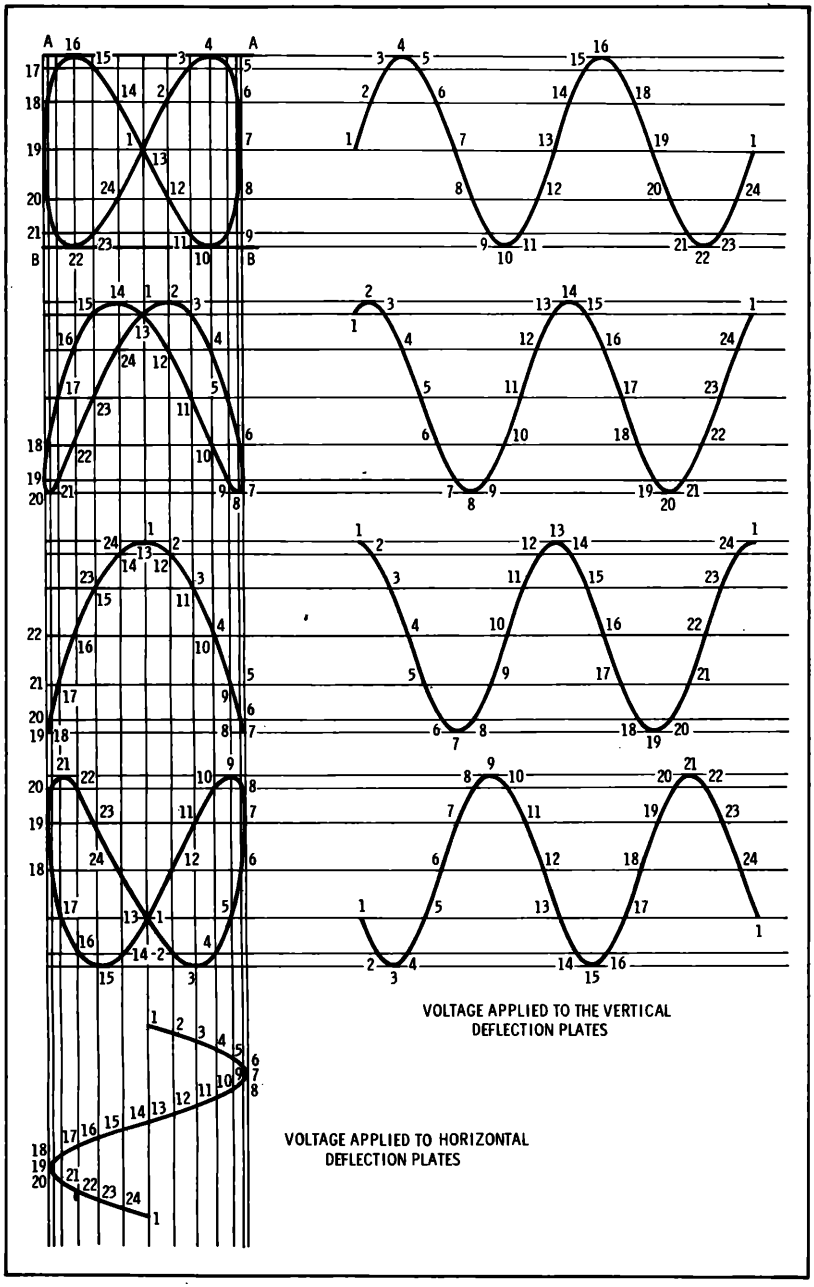


Fig. 4-12. Lissajous pattern produced by a 2-to-1 frequency ratio.

ample, Fig. 4-13 shows the reference Lissajous pattern for a 2-to-3 frequency ratio. We observe that there are two points of tangency along the side, and three points of tangency along the top of the pattern.

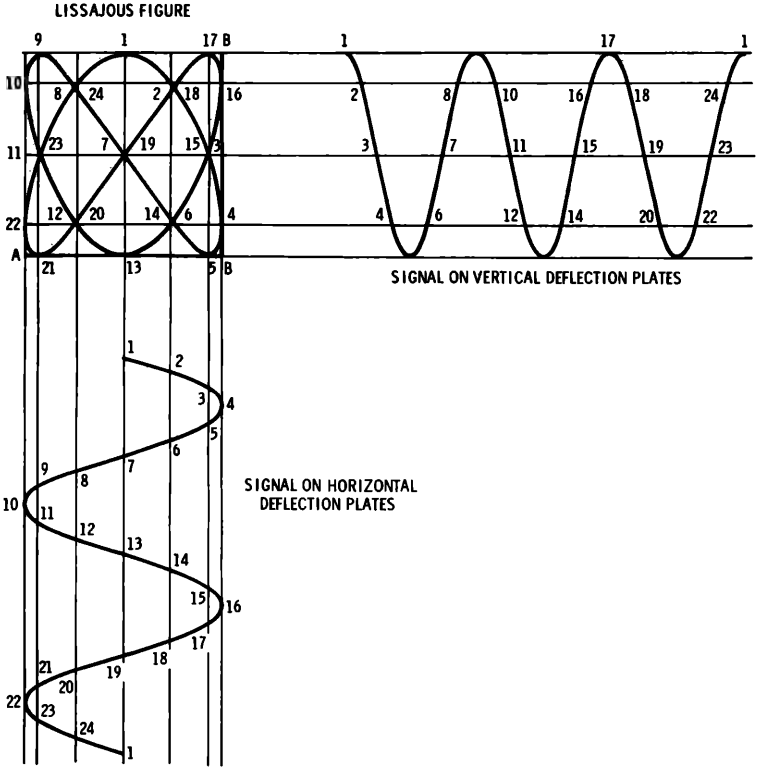


Fig. 4-13. Lissajous pattern for a 2-to-3 frequency ratio.

Fig. 4-14 depicts the reference Lissajous patterns for 1-to-1, 2-to-1, 3-to-1, 5-to-1, 1-to-10, 3-to-5, and 5-to-6 frequency ratios. In practice, it is difficult to use frequency ratios greater than 1-to-10 in calibration procedures with Lissajous patterns. The dial setting is very critical and any slight change in oscillator or line frequency will cause the pattern to move rapidly and change its waveform. Therefore, calibration at frequencies greater than 600 Hz is not entirely practical with the simple test setup of Fig. 4-11. Readers who wish to learn about

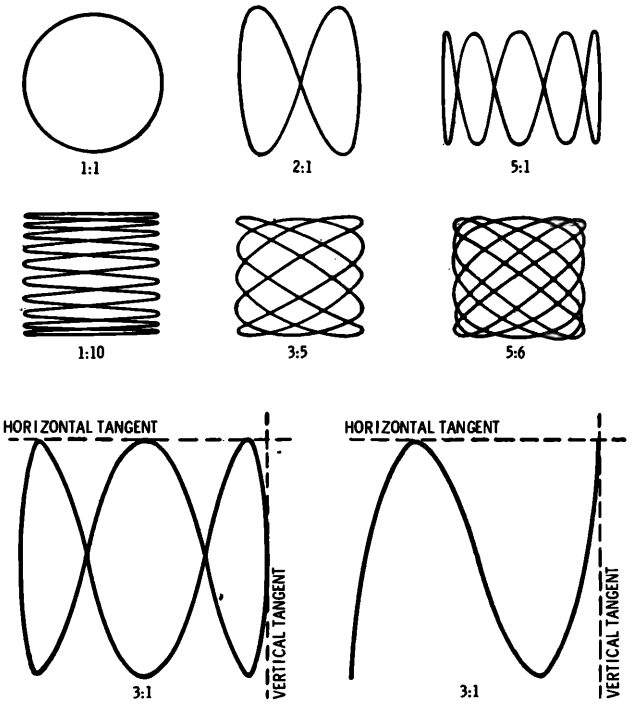


Fig. 4-14. Lissajous patterns for various frequency ratios.

more elaborate calibration test procedures are referred to test-equipment maintenance and calibration books.

Although a simple crt arrangement can be used in certain types of tests, somewhat more elaborate power supplies and control circuitry are usually desirable. Fig. 4-15 shows typical general purpose cathode-ray tube circuitry. Most vectorscopes utilize this type of crt arrangement. We observe that both low-voltage and high-voltage power supplies are provided. The availability of a low-voltage power supply enables the crt to be operated as a conventional oscilloscope with the aid of supplementary electronic units. Note also that vertical- and horizontal-centering controls are provided. This feature permits the operator to move the resting position of the beam to any point on the crt screen, as illustrated in Fig. 4-16. We also observe in Fig. 4-15 that blocking capacitors C7 and C8 are provided between the vertical- and horizontal-input terminals

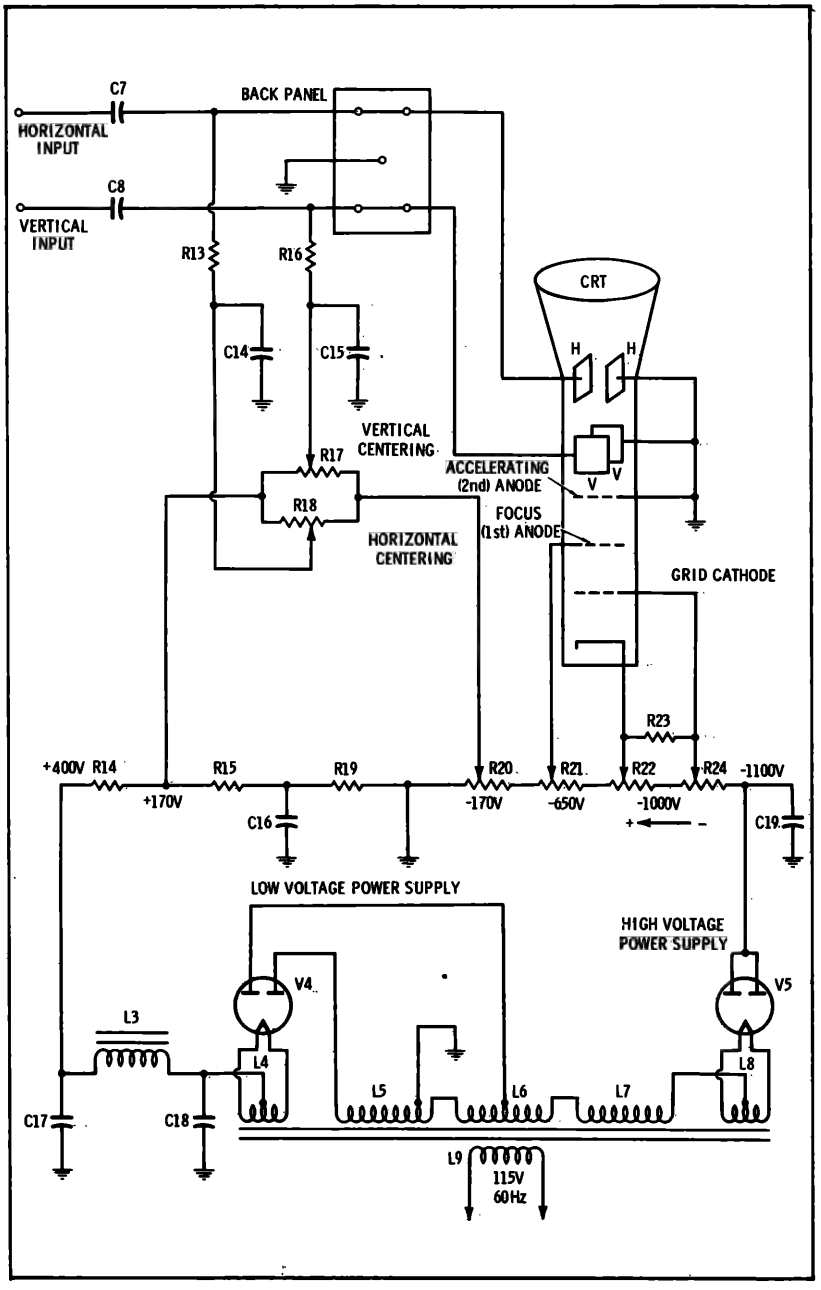


Fig. 4-15. General purpose crt circuitry.

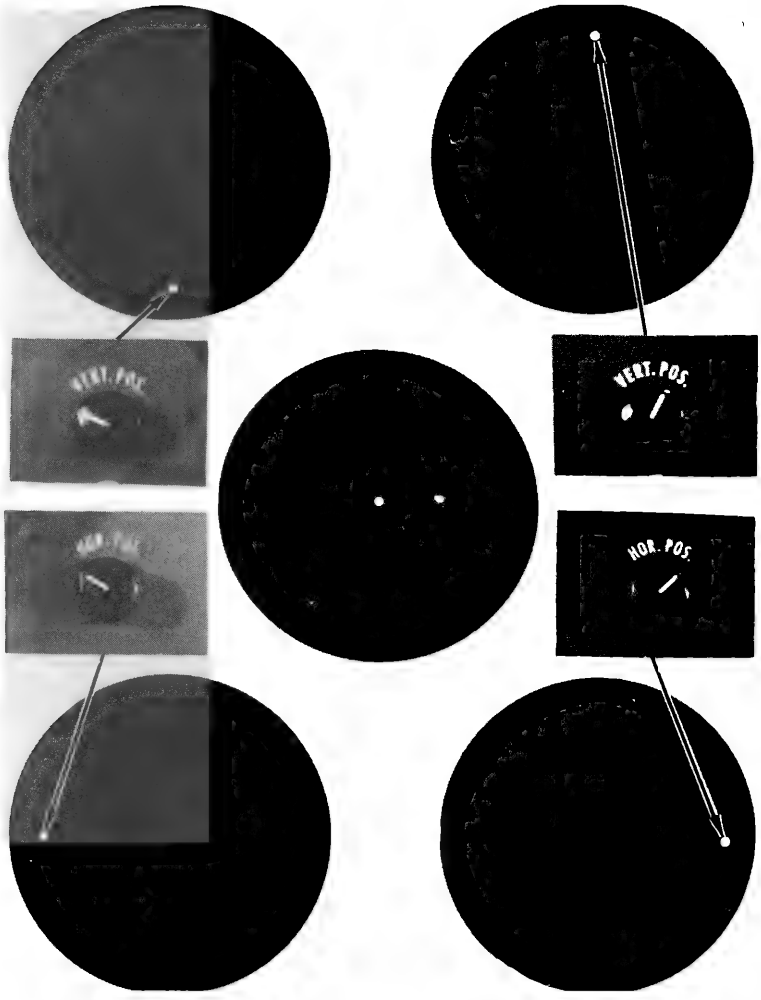


Fig. 4-16. Action of positioning (centering) controls.

and the crt deflection plates. This feature ensures that the beam will not be shifted in case the input signal has a dc component.

VIDEO-FREQUENCY SERVICING APPLICATIONS

When a weak-picture trouble symptom develops in a tv receiver, the signal attenuation may be occurring in the video

amplifier. Hence, it is necessary to check the gain of the video amplifier. A test setup as depicted in Fig. 4-17 is suitable. Many service shops have test-pattern generators available, and this is a useful signal source. A test pattern appears on the picture on the picture-tube screen, as illustrated in Fig. 4-18A, and has the corresponding video waveform shown in Fig. 4-18B. The gain test is made by checking in turn at the input and output of the video amplifier, as depicted in Fig. 4-17. The

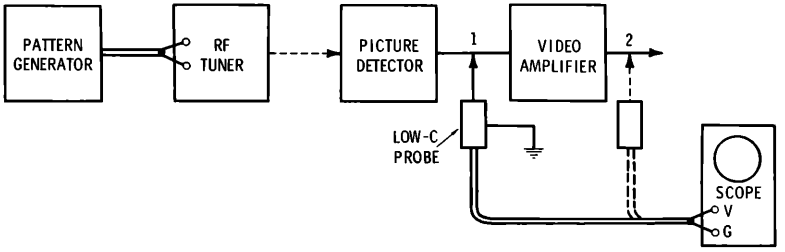
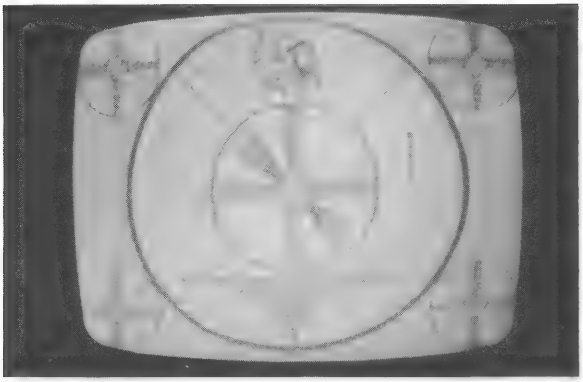


Fig. 4-17. Checking the gain of a video amplifier.

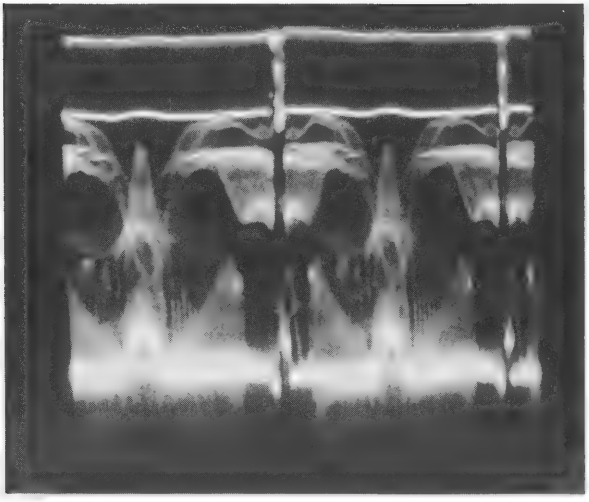
ratio of the pattern heights indicates the gain of the video amplifier. A gain of 50 times is typical; the normal figure is always specified in the receiver service data.

In color-tv receiver servicing, an oscilloscope is often used as a vectorscope. With reference to Fig. 4-19, most service-type scopes have a rear terminal board with link connections to the deflection-plate terminals. When the links L1 and L2 are opened, a signal can be coupled to one deflection plate through a 0.01-μF capacitor. The opposing deflection plate is grounded for ac by means of a 0.01-μF bypass capacitor. In turn, the scope can be used as a vectorscope in accordance with previous discussion. A typical vectorgram is illustrated in Fig. 4-20, as it is displayed on the crt screen.

Tests must be made in high-level circuits when a signal is coupled directly to the deflection plates of a crt. If tests are made in low-level circuits, the signals must be stepped up through the vertical and horizontal amplifiers of the scope. For example, if we wish to make a vectorscope test at the outputs of the R – Y and B – Y demodulator in a color-tv receiver, it is necessary to apply these signals to the vertical-input and horizontal-input terminals of the scope. However, this procedure is not always practical, because the horizontal ampli-



(*A*) *On screen of picture tube.*



(*B*) *Waveform on crt screen.*

Fig. 4-18. Test-pattern displays.

fier of the scope may be inadequate to amplify the demodulator-output waveform without distortion. Therefore, a scope that is applied in this type of test needs to have a horizontal amplifier bandwidth of at least 1 MHz.

INTERMEDIATE-FREQUENCY TESTS

The most common application of an oscilloscope in i-f tests is in sweep-alignment procedures. Typical test connections are

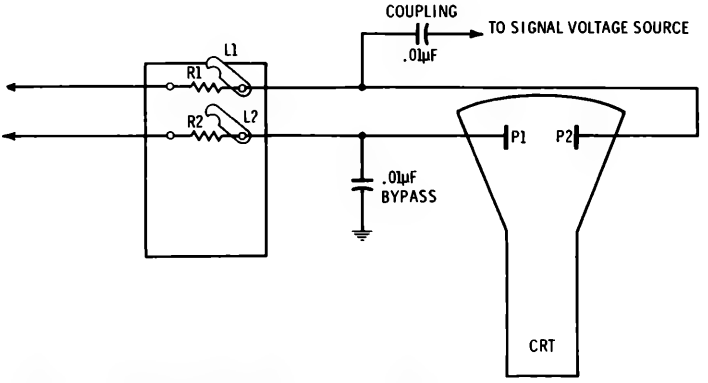


Fig. 4-19. Applying video signal voltage directly to vertical-deflection plates.

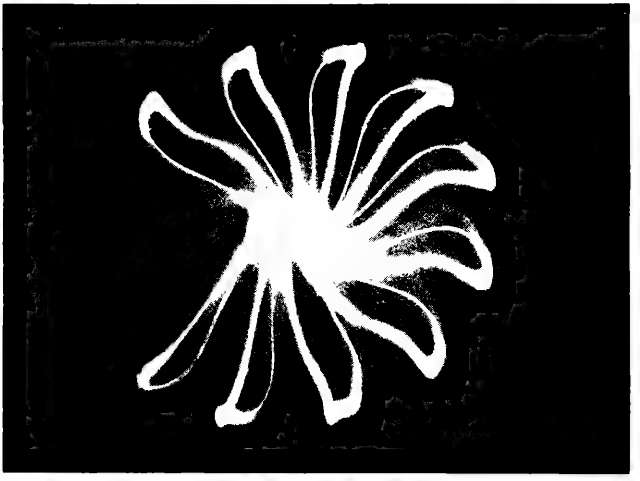


Fig. 4-20. Typical vectorgram.

shown in Fig. 4-21. The output from an i-f sweep-frequency generator is applied to a floating tube shield over the mixer tube in the receiver chassis. In turn, the test signal is capacitively coupled to the plate of the mixer tube, and the mixer circuit operation is not disturbed. Note that the scope is connected through an isolating resistor to the load resistor. This isolating resistor provides a low-pass filter action in combination with the capacitance of the scope input cable. Filter action provides sharper marker indication on the response curve than is otherwise obtainable.

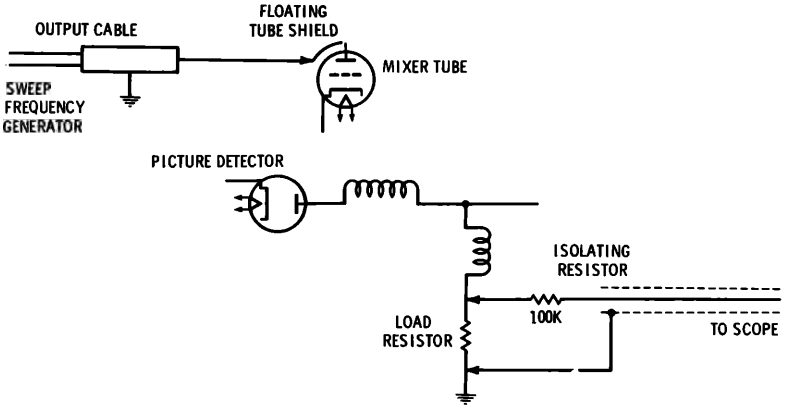
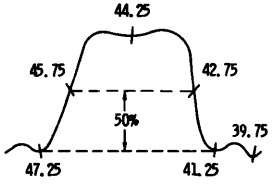


Fig. 4-21. Test connections for display of an i-f response curve.

It is good practice to clamp the agc line on the receiver chassis with fixed bias voltage. This prevents the response curve from becoming distorted due to agc voltage variation. The receiver service data will specify a suitable value of clamp voltage and the recommended test connections to be used with a particular receiver. Practically all tv i-f amplifiers operate in the 40-MHz region. In turn, a typical response curve has the frequency distribution shown in Fig. 4-22. As noted previously, key frequencies are identified along the curve by means of markers. Most modern sweep-frequency generators contain built-in marking functions. However, any sweep generator can be supplemented by a marker generator.

Fig. 4-22. I-f response curve, with markers.



RADIO-FREQUENCY TESTS

The most common application for the oscilloscope in rf tests is for the display of rf response curves in sweep-alignment procedures. Test connections are exemplified in Fig. 4-23. The rf sweep signal is applied to the antenna-input terminals of the

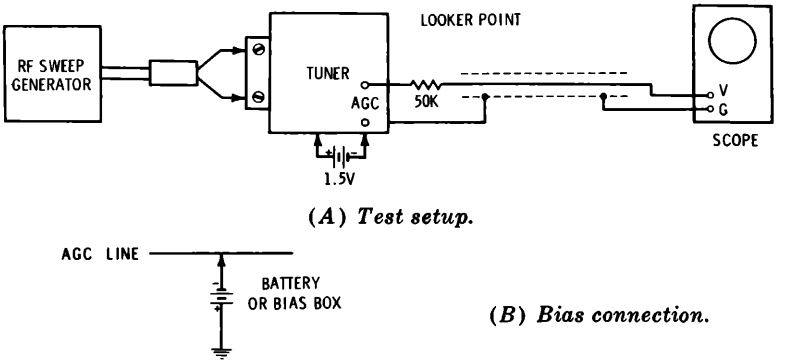


Fig. 4-23. Test connections for rf sweep alignment.

rf tuner, and the oscilloscope is connected through an isolating resistor to the "looker point" on the rf tuner. The agc line is then clamped with a fixed bias voltage, such as 1.5 volts. Procedural details for specific tuners will be found in the receiver service data. Twelve vhf channels are available, with a frequency range from 54 to 216 MHz. Picture- and sound-carrier frequencies are the key marking points on the frequency-response curve, as seen in Fig. 4-24.

Color-tv receivers may be checked by means of the video sweep modulation (vsm) technique, as noted previously. This is basically an overall check of the picture-channel frequency response. Fig. 4-25 shows the plan of the test arrangement. A marker generator is utilized that has a built-in wideband modulator. An external rf modulator unit can also be used. Note

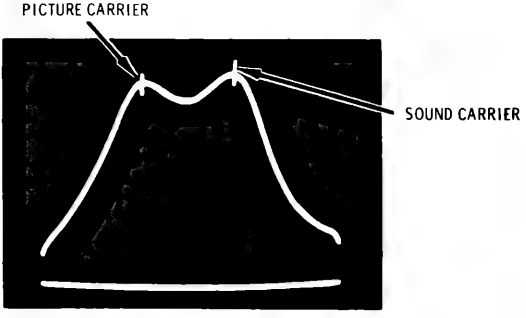


Fig. 4-24. Rf frequency-response curve.

that a video-frequency sweep signal is applied to the modulator through an absorption-marker box. The video-frequency sweep signal (50 kHz to 4.5 MHz) is thereby modulated on the rf carrier frequency provided by the marker generator. This rf carrier frequency is set to the picture-carrier frequency of the vhf channel to which the receiver is tuned. The scope is connected through a demodulator probe to the output of the video amplifier in this example.

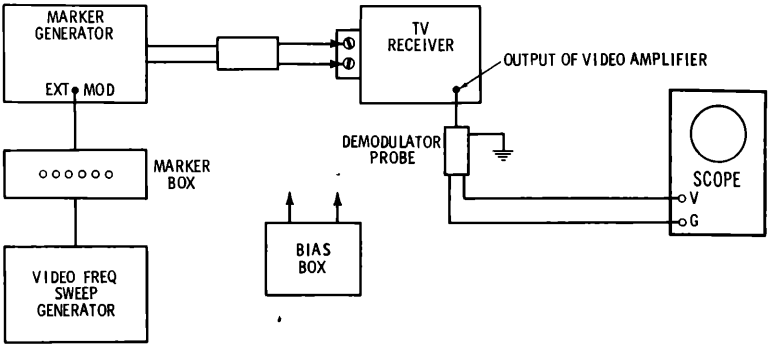


Fig. 4-25. Vsm check of overall picture-channel response.

We recognize that although a vhf test signal is applied to the rf tuner in a vsm arrangement, this is a specialized type of signal in which a video-frequency sweep signal is encoded. If the rf, i-f, and video amplifiers are operating properly as a team, a response curve is displayed on the scope screen as exemplified in Fig. 4-26. This response is essentially the same as obtained if the video amplifier is swept by itself. The most usual distortion is subnormal bandwidth, caused by misalignment of the rf or i-f amplifier, by a defect in the video ampli-

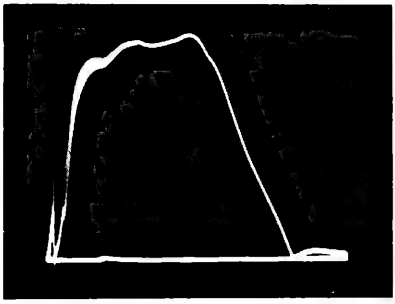


Fig 4-26. Response curve obtained from vsm check.

fier, or by off-frequency operation of the local oscillator in the rf tuner.

Fig. 4-27 shows how absorption markers appear as dips along a response curve. Absorption markers are preferable to beat markers when working with video-frequency sweep signals, because any problems of spurious markers are avoided. In other words, when a beat marker is used with a video-frequency sweep signal, we will often encounter various spurious markers on the curve due to cross-beats between signal harmonics. Spurious markers can be confusing and misleading. However, when absorption markers are used there are no harmonics associated with the marker and no possibility of spurious indication.

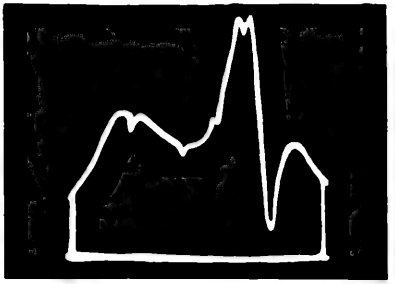
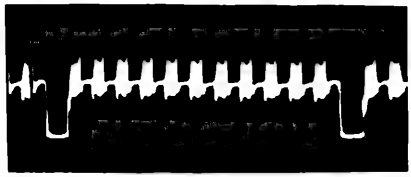


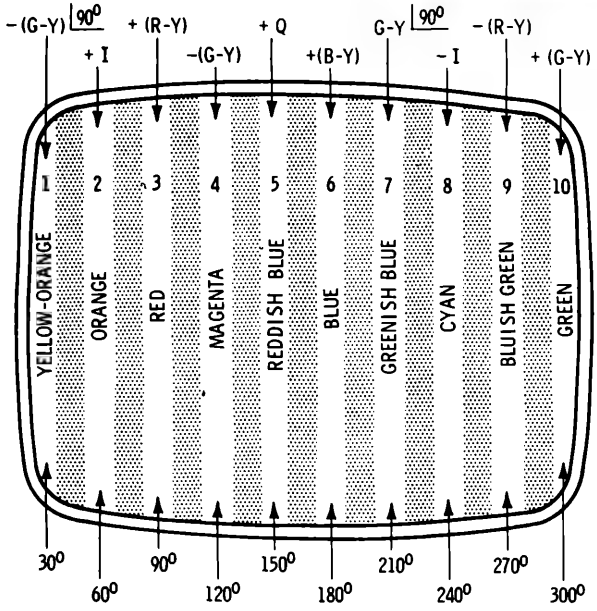
Fig. 4-27. Absorption markers on a bandpass-amplifier response curve.

COLOR-SIGNAL TESTS

Although there are several types of color-tv test signals, the keyed rainbow signal illustrated in Fig. 4-28A is usually preferred by technicians. This signal is also called a color-difference bar signal, a linear phase sweep, or a sidelock signal. It consists of 11 bursts of 3.58-MHz sine-wave voltages between consecutive horizontal-sync pulses. The output from a keyed-rainbow generator can be applied to a color-tv receiver, as shown in Fig. 4-29, to make numerous tests of circuit action. One of the basic tests is a check of the chroma-demodulator output waveforms. Thus, the scope is applied in turn at the output terminals of the R – Y, B – Y, and G – Y chroma demodulators. These demodulators are phase detectors. Since each successive burst in the test signal has a phase advance, characteristic output waveforms are produced.

(*A*) *Keyed rainbow signal.*





(*B*) *Chroma phases or bar display.*

Fig. 4-28. Keyed rainbow signal and bar pattern.

Normal chroma-demodulator output waveforms are illustrated in Fig. 4-30. We observe that the R – Y waveform nulls at the sixth pulse, the B – Y waveform nulls at the third and ninth pulses, and the G – Y waveform nulls at the first and seventh pulses. If the null points occur incorrectly, the technician checks the chroma-demodulator circuits for a defective component. Note in passing that the hue control of the color receiver must be correctly adjusted during the test, or all of the null points will be displayed incorrectly on the crt screen. Peak-to-peak voltages of the waveforms are also specified in the receiver service data. If the R – Y output signal happened to be weak, for example, the color picture would be repro-

duced with weak red hues. The waveforms shown in Fig. 1-30 can be traced through the chroma-amplifier circuits to the grid terminals of the color picture tube.

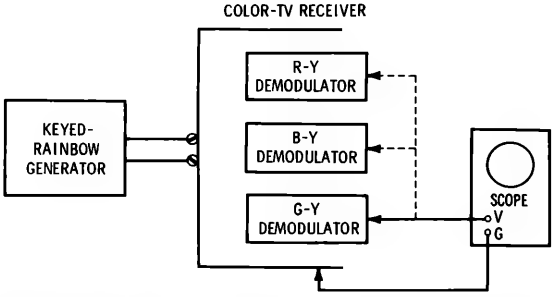


Fig. 4-29. Checking the chroma-demodulator output waveforms in a color-tv receiver.

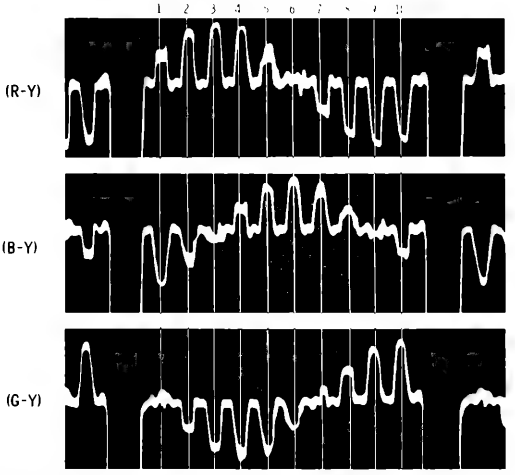


Fig. 4-30. Normal chroma-demodulator output waveforms.

CHAPTER 5

INTERMEDIATE AND LABORATORY OSCILLOSCOPES

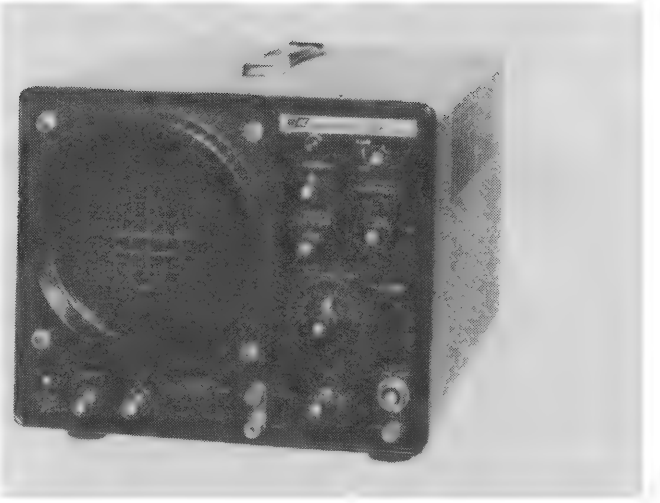
Lab oscilloscopes differ from *service* oscilloscopes in several respects. For example, a lab scope has extended high-frequency response to 15 MHz or more, with calibrated triggered sweeps and a calibrated vertical attenuator. On the other hand, typical service-type scopes seldom have frequency response above 5 MHz, with free-running sweep action, and an uncalibrated vertical attenuator. Another distinction concerns comparative deflection linearity. That is, a lab scope has highly linear vertical- and horizontal-deflection linearity, whereas a service scope provides moderate deflection linearity. We will also find that a lab scope permits any chosen portion of a waveform to be "picked out" and displayed, whereas a service scope has very limited ability to separate one portion of a waveform from its total excursion.

INTERMEDIATE OSCILLOSCOPES

Intermediate scopes are more elaborate than conventional service scopes, although they do not provide all of the facilities and accuracy of lab scopes. The intermediate scope provides operating convenience at the service bench, and is also able to yield much more test data than a conventional scope. This increased utility cannot be realized, however, by an inexperienced operator. That is, the instrument functions must be

clearly understood, and a fairly comprehensive knowledge of waveform analysis is required. Accordingly time and study must be invested by the beginner, if he is to realize the full potential of a sophisticated type of oscilloscope.

A typical intermediate oscilloscope is illustrated in Fig. 5-1. It provides a vertical-amplifier frequency response from dc to 10 MHz at a sensitivity of 0.01 volt per centimeter, or 0.025



Courtesy Dynascan Corp.

Fig. 5-1. Service-type triggered-sweep oscilloscope.

volt per inch, approximately. Triggered and automatic sweep functions are provided, as explained in greater detail subsequently. Sweep speeds range from 0.5 microsecond per centimeter to 0.5 second per centimeter. A sweep-magnification facility produces a maximum sweep speed of 0.1 microsecond per centimeter. The horizontal amplifier has a frequency response from dc to 800 kHz at a sensitivity of 0.3 volt per centimeter.

The vertical amplifier of an intermediate scope does not usually include a *delay line,* whereas a lab scope employs a delay line, as included in Fig. 5-2. This delay line is similar to the delay line in a color-tv receiver, and has the function of "storing" the vertical-input signal for a small fraction of a second. In turn, a fast-rise pulse can be displayed without the loss of any portion of the leading edge, as exemplified in Fig.

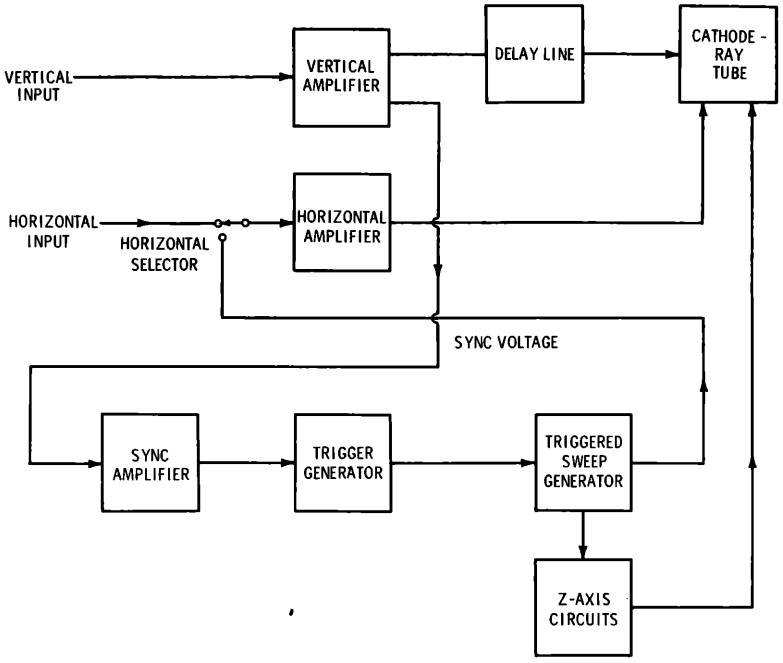


Fig. 5-2. Basic lab oscilloscope.

5-3. Functionally, the delay line permits the sweep to "get started" before application of the signal to the vertical-deflection plates. Since this requirement is comparatively minor in tv service procedures, intermediate scopes generally do not include delay lines.

Most intermediate scopes have calibrated step attenuators, and all lab scopes include this feature. Highly stable vertical amplifiers are utilized, so that the amplifier will remain accurately calibrated over a long period of time. In turn, the vertical step attenuator is calibrated in terms of peak-to-peak voltage per centimeter of deflection. For example, 11 steps may be provided with a range from 10 millivolts per centi-

(*A*) *Input pulse.* (*B*) *Without delay.* (*C*) *With delay.*

Fig. 5-3. Function of delay line in display of a fast-rise pulse.

meter to 20 volts per centimeter. Accordingly, when the pattern height is observed on the crt screen, and the setting of the vertical attenuator is noted, a simple calculation gives the peak-to-peak voltage of the vertical-input signal.

Intermediate scopes have calibrated horizontal sweep-time controls, as depicted in Fig. 5-4. This feature enables the operator to measure the rise time of a waveform, as shown in Fig. 5-5. Note that the rise time, "T," is defined as the time re-

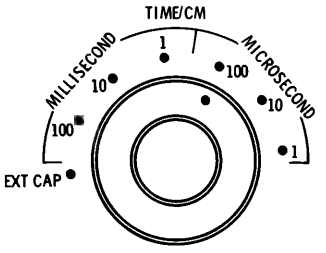


Fig. 5-4. Typical horizontal sweep-time control for a triggered-sweep oscilloscope.

quired for the signal voltage to rise from its 10% level to its 90% level. In other words, ideal pulses or leading edges do not exist in practice, and any complex waveform displayed on the crt screen has a definite rise time, although it might be very short in some situations. Fig. 5-6 shows a comparison of ideal and practical square waves. An ideal waveform rises instantaneously and has perfectly square corners, whereas a practical waveform has a definite rise time and has rounded corners. Rise time is defined as the interval from 10% to 90% on the leading edge, in order to eliminate consideration of cornering effects. That is, cornering is not directly associated with rise time.

Most intermediate scopes provide trigger-polarity and level controls. This permits the operator to trigger the sweep at any

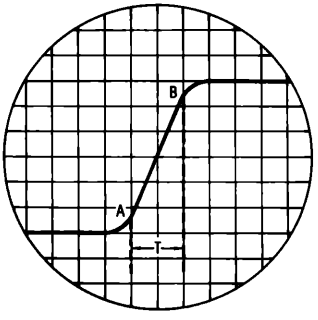


Fig. 5-5. Rise time.

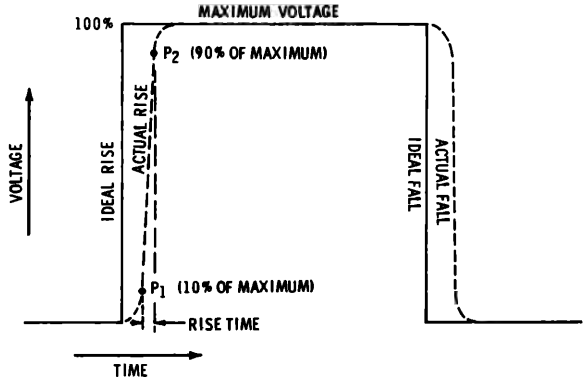
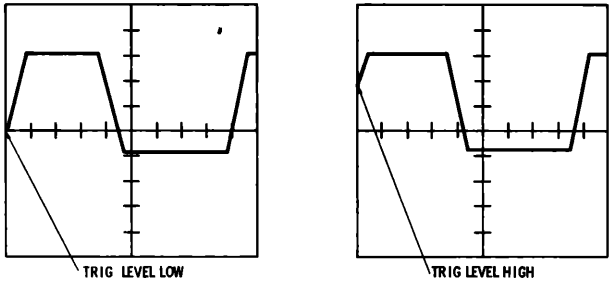
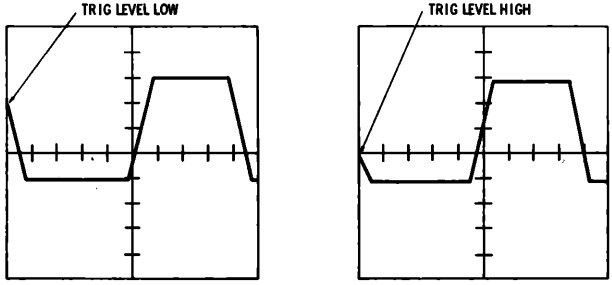


Fig. 5-6. Comparison of ideal and practical square waves.

point on the leading or trailing edge of a waveform, as shown in Fig. 5-7. If a positive trigger polarity is used, the sweep will be triggered somewhere along the leading edge of the wave-



(A) Positive slope triggering.



(B) Negative slope triggering.

Fig. 5-7. Sweep can be triggered at any point on the leading or trailing edge of a waveform.

form. On the other hand, if a negative trigger polarity is used, the sweep will be triggered somewhere along the trailing edge of the waveform. The exact point at which triggering occurs is determined by the setting of the trigger-level control. These functions are important in various applications, because a small section of a waveform can be picked out and then expanded or magnified on the screen as exemplified in Fig. 5-8. By way of comparison, a conventional service scope is quite limited in this kind of application.

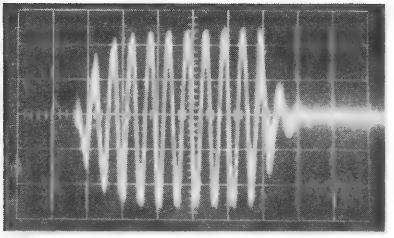


Fig. 5-8. Color burst on screen of a triggered-sweep oscilloscope.

Automatic triggering is provided in most lab and intermediate scopes. This function is quite similar to a free-running sweep in some respects, and to triggering operation in other respects. The chief disadvantage of automatic triggering is that the operator cannot control the triggering point along a waveform. As in the case of free-running sweep, the sync action always occurs just as the waveform starts to rise from the zero level. On the other hand, there is a considerable advantage to the automatic-triggering function, because a horizontal trace is always present on the crt screen, even when no vertical-input signal is applied. This trace in most cases, is repeated 50 times a second. It is easier to use automatic triggering than a free-running sweep, because the sync signal is processed by clipping and differentiating so that no sync-amplitude control is required.

When automatic triggering is in use, the sweep-time control can be set to any desired point. If the sweep speed is set to a higher value than the signal frequency, only the first portion of the vertical-input waveform will be displayed. Note that there is no overlapping pattern or multiple traces, as would be the case with a free-running sweep. That is, any triggered-sweep section includes a hold-off, or *lockout* circuit. This is an automatic bias arrangement that cuts off the sweep oscillator until the incoming signal cycle is completed. Then the cutoff

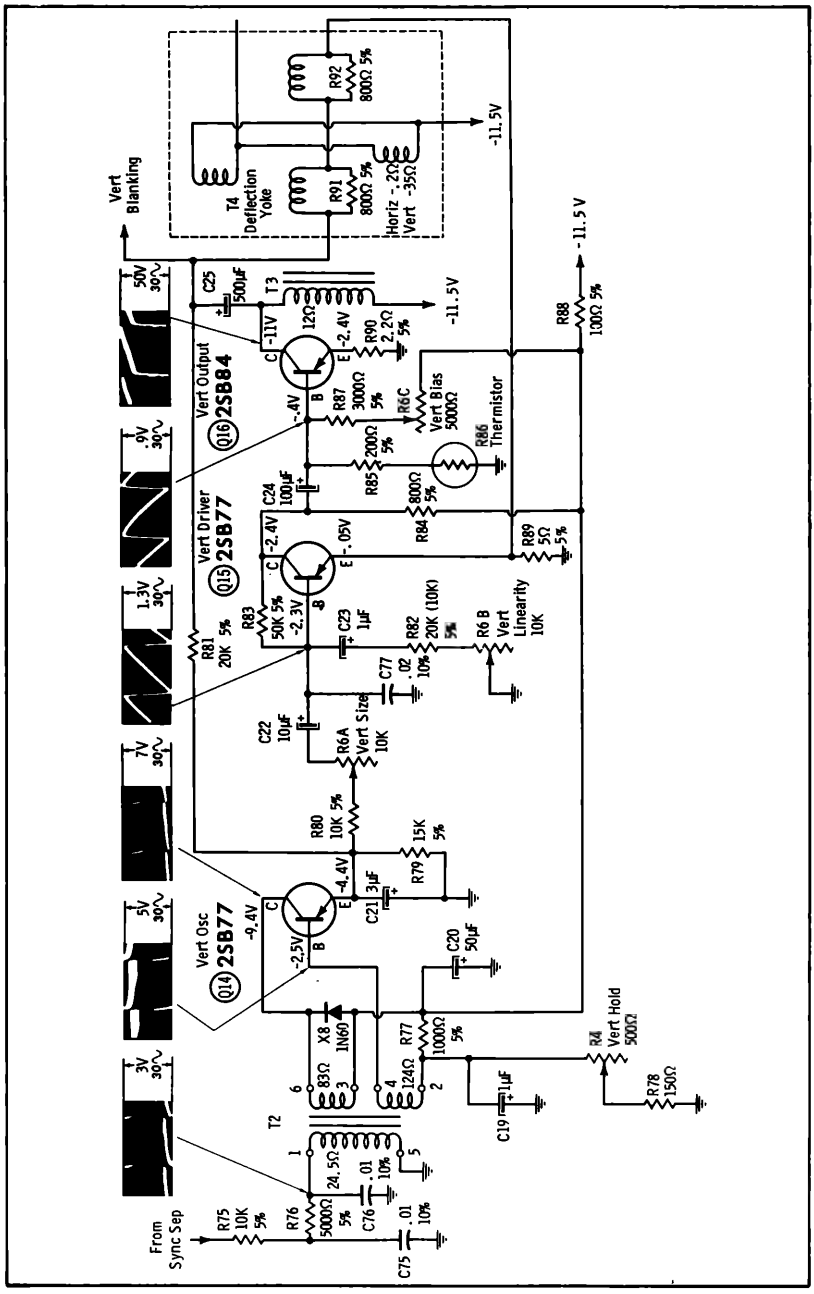


Fig. 5-9. Vertical-sweep configuration.

bias is removed so that the sweep oscillator can be triggered again at the same point on the signal cycle.

Intermediate scopes designed for tv service applications often provide preset 30-Hz and 7875-Hz sweep-frequency positions. This is an operating convenience, because the tv technician can change over from vertical-rate to horizontal-rate waveforms merely by throwing a switch. It is standard practice in tv service work to display two cycles of a waveform, as the waveforms in Fig. 5-9 and 5-10. This is the presentation that we find in receiver service data. We note in the foregoing diagrams that waveform amplitudes are quite different at various points in the circuits. However, any waveform will be automatically locked in sync when the automatic-triggering function of the scope is utilized.

APPLICATIONS OF TRIGGERED-SWEEP OSCILLOSCOPES

Since a triggered-sweep scope has a calibrated time base, frequency measurements can be made (Fig. 5-11). That is, the number of horizontal divisions over a complete cycle is observed on the graticule. In this example, one cycle occupies four divisions. Then the sweep-time setting is noted on the front-panel scale, and this reading is multipled by the number of divisions that were counted. For example, if the sweep speed happens to be 0.2 microsecond per centimeter it is evident that the time for a complete cycle in Fig. 5-11 will be 0.8 microsecond. In turn, frequency is equal to the reciprocal of the waveform period, or, the frequency of the waveform will be 1.25 MHz. This is a useful method for checking the calibration of a service-type a-m signal generator, or audio oscillator.

Pulse width is measured in time units between the 50% amplitude points of the waveform, as shown in Fig. 5-12. If the width of a horizontal sync pulse is approximately 5 microseconds, the rise time of that sync pulse, or that of any fast-rise waveform, is affected by the bandwidth of the circuit through which the waveform is passed. For example, the high-frequency cutoff point of an audio amplifier can be easily determined from the rise time in a square wave test. For example, we apply the output from a square-wave generator to an audio amplifier. Then we calculate the rise time of the reproduced

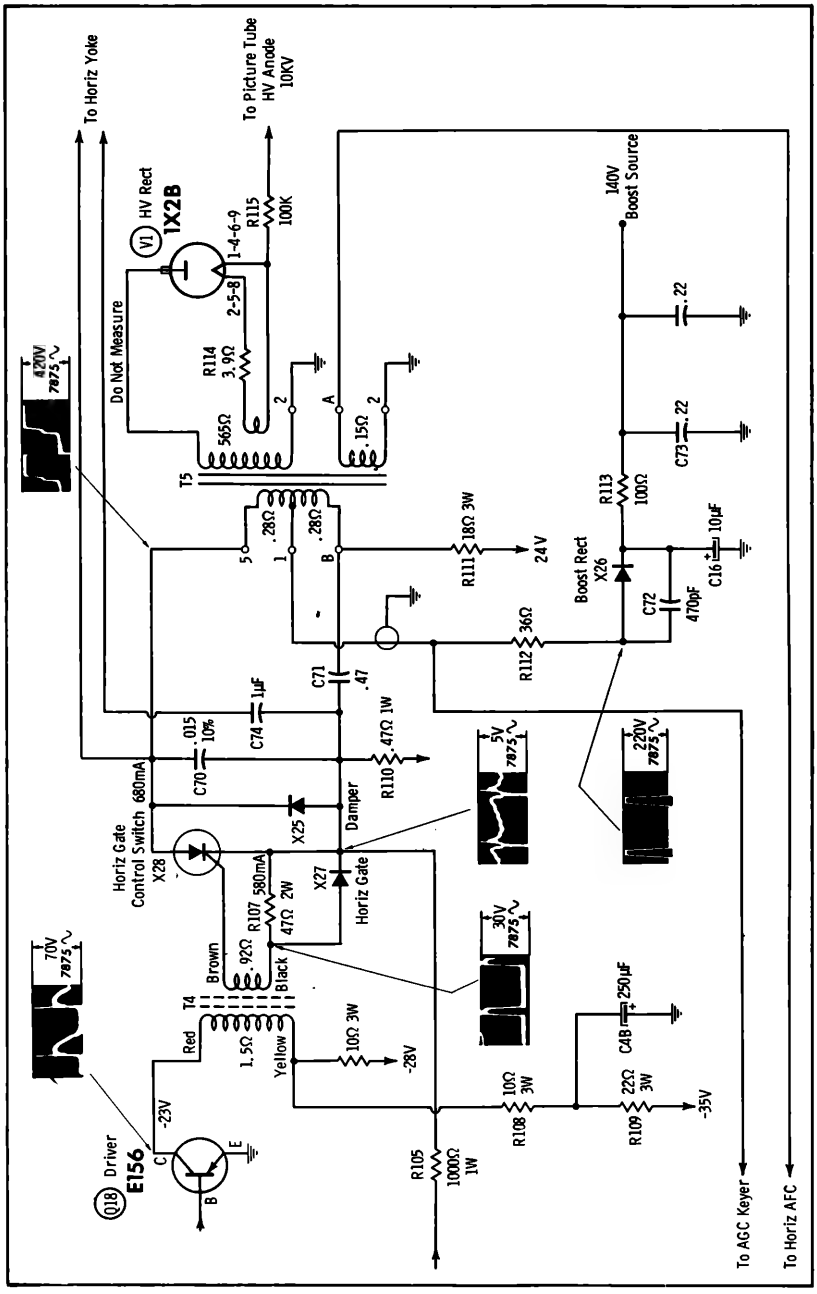


Fig. 5-10. Horizontal-sweep configuration.

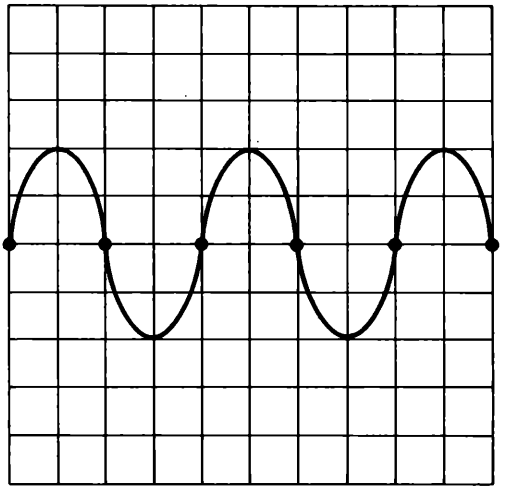


Fig. 5-11. Frequency measurement with a triggered-sweep oscilloscope.

square wave, take the reciprocal of three times that rise time, and we have the cutoff frequency. Therefore, if the rise time of the square wave reproduced at the amplifier output is 22 microseconds, we divide 66 microseconds into 1, and find that the cutoff frequency of the amplifier is, approximately 15 kHz.

The square-wave response of an amplifier also indicates its low-frequency cutoff point. In the case of a dc-coupled amplifier, the low-frequency cutoff occurs at zero frequency. However, any ac-coupled amplifier has a low-frequency cutoff point above zero. As noted previously, the top of a reproduced square wave may not be level and may slope. This distortion is called *tilt*. An example of tilt is shown in Fig. 5-13. Tilt is defined as the ratio of amplitudes V_T and V_P. For example, if V_T occupies two divisions, and V_P occupies 20 divisions, the tilt of the square wave is equal to 0.1, or 10%. To find the value of the low-frequency cutoff point, we multiply the square-wave frequency by 1/3 of the percentage tilt. Thus, if the square-

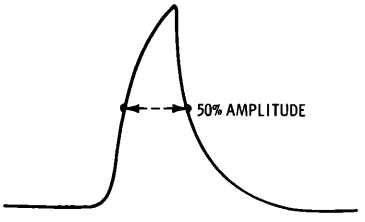


Fig. 5-12. Measurement of pulse width.

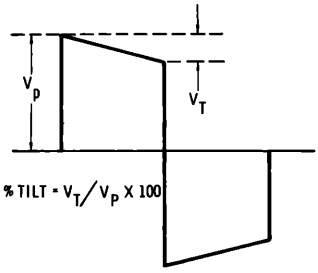


Fig. 5-13. Tilt.

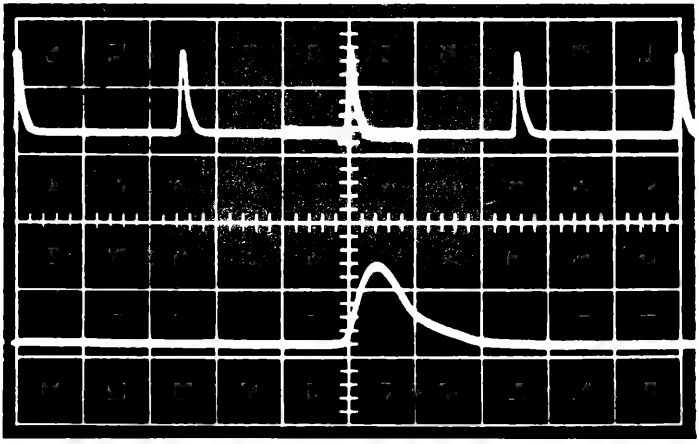
wave frequency is 100 Hz, and the percentage tilt is 10%, the low-frequency cutoff value is approximately 330 Hz.

FUNCTIONS OF LABORATORY OSCILLOSCOPES

Various functions are provided in lab scopes that are not included in the intermediate scopes. For example, two vertical-input channels may be available for dual-beam displays, as depicted in Fig. 5-14. This kind of presentation is useful to compare circuit actions at two different points in a configuration during design work, to monitor input and output waveforms of an electronic device, to measure phase differences, or to display a main waveform at slow sweep speed and some chosen detail in the same waveform at high sweep speed.

When a lab scope is to be used in widely different applications, it is customary to employ a basic frame into which various preamplifiers, time bases, and signal processors can be plugged as the application requires. For example, a display scanner plug-in unit is shown in Fig. 5-15. Preamplifier plug-in units include very wideband response up to thousands of megahertz, narrow-band units with very high sensitivity, push-pull input units, dual-trace amplifiers, and logarithmic amplifiers.

Sweep plug-in units include a *delayed-sweep* function, whereby an applied trigger pulse starts the time base after a predetermined length of time. This feature is useful to check pulse trains, such as utilized in digital computers. Specialized delayed-sweep units are also used to measure the jitter in a waveform. Jitter refers to lack of a precise repetition rate in a pulse train, or other repetitive waveform. Another type of plug-in unit produces a marker on the main waveform, at which an expanded display is being shown in a dual-trace



(*A*) *Screen pattern.*

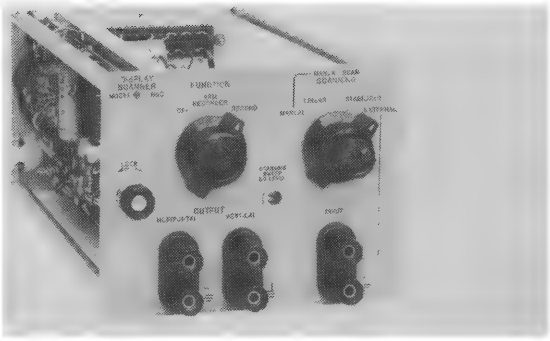
(*B*) *Plug in amplifier.*

Courtesy Hewlett Packard Co.

Fig. 5-14. Dual-beam unit and display.

pattern. Still another type of plug-in unit is designed for testing cables, transmission lines, strip lines, connectors, and other high-frequency devices.

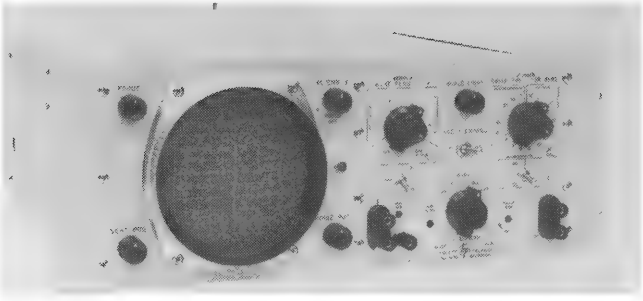
Lab scopes are also designed for rack mounting, as shown in Fig. 5-16. This is the preferred design for installation in permanent locations and for monitoring applications, as in radar systems and television broadcast stations. Rack-mounted scopes may contain a built-in power supply, or may be operated from a separate power source. Any application ordinarily encountered in factories, design laboratories, or



Courtesy Hewlett Packard Co.

Fig. 5-15. Display scanner plug-in unit.

scientific facilities can be met by a rack-mounted oscilloscope. For example, an industrial-electronics application might require a scope to monitor welding currents, whereas an operating room might require a scope to monitor heart beats.



Courtesy Hewlett Packard Co.

Fig. 5-16. Rack-mounted oscilloscope.

Some lab scopes feature *pattern storage* and *variable persistence*. For example, a storage scope can "hold" a display for several hours, if desired. At any time, the display can be "erased" by pushing a corresponding button. Persistence denotes the length of time that it takes for a pattern to fade to 10% of its original brightness. Some lab scopes feature variable persistence, from 0.2 second to more than a minute.

Crt screen sizes range up to 10 inches in diameter. There is a trend for compact and portable high-performance scopes,

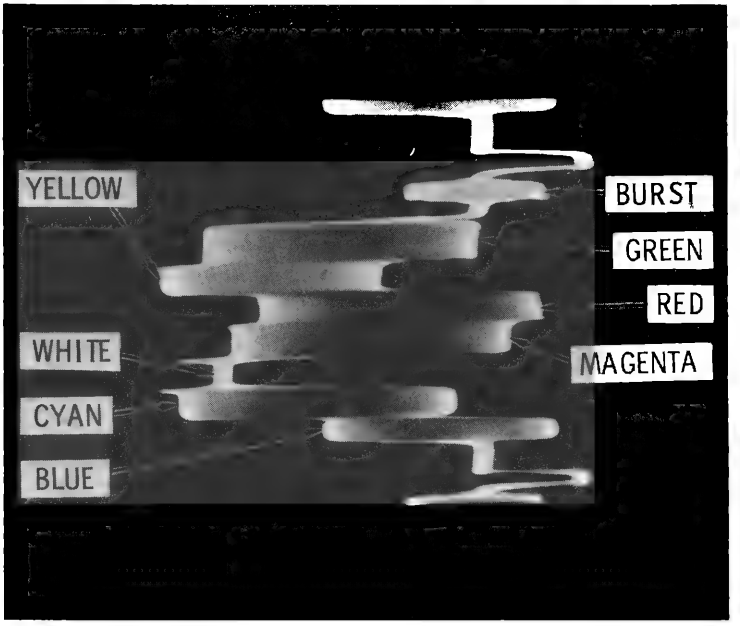


Fig. 5-17. NTSC color-bar signal.

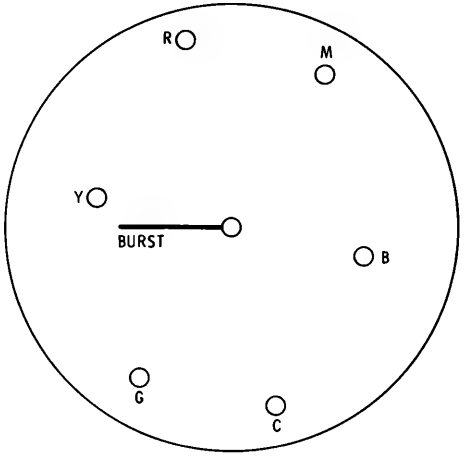


Fig. 5-18. Vectorscope graticule for a NTSC signal.

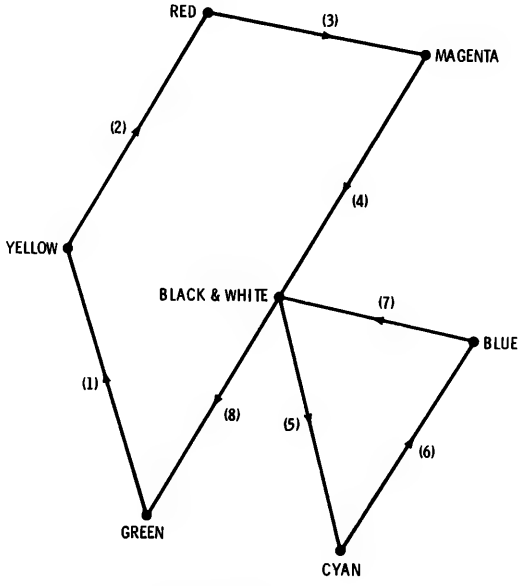


Fig. 5-19. NTSC vectorgram pattern.

which may also be battery operated. These scopes find useful application in field-engineering work.

Color-tv broadcast stations utilize lab scopes as vectorscopes. The input signal to the vectorscope is an NTSC signal, as exemplified in Fig. 5-17. Note that this type of color test signal is also used in service shops, although not nearly to the extent as keyed-rainbow test signals. The NTSC signal requires a corresponding vectorscope graticule, as depicted in Fig. 5-18. An NTSC vectorgram pattern is developed as shown in Fig. 5-19. If the color-tv system characteristics are normal, the corners of the pattern will fall within the small circles of the graticule arrangement.

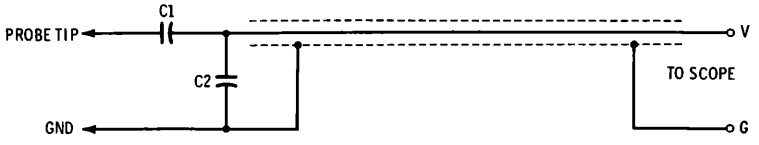
CHAPTER 6

OSCILLOSCOPE PROBES AND AUXILIARY DEVICES

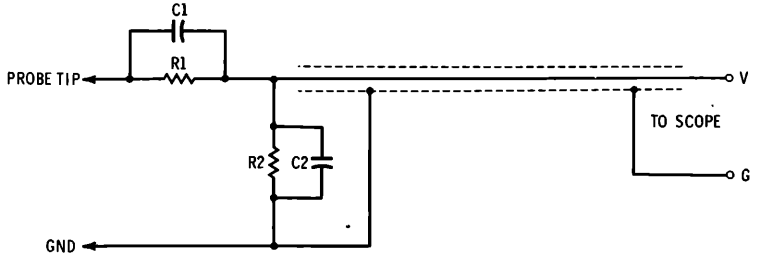
Many types of probes and accessories are available to increase the utility of an oscilloscope for particular applications. For example, various types of graticules and crt light filters may be used. Low-capacitance and demodulator type probes were described previously; the numerous other types can be utilized. Wheeled scope carts provide mobility when a scope must be moved about from one test location to another. Viewing hoods are useful for observing screen patterns in high ambient light situations, and for inspection of dim high-speed detail in certain waveforms. Special cameras can be employed to photograph waveform displays. These and other auxiliary devices contribute to operating convenience, as well as providing additional fields of application for the oscilloscope.

PROBES

High-voltage probes are used when the potential at the point of test exceeds 600 volts. This type of probe is utilized extensively in laboratory and engineering applications and is sometimes employed in tv service shops. A high-voltage probe avoids damage to the scope input section and also prevents overload of the vertical amplifier. As depicted in Fig. 6-1, two basic configurations are available. The capacitance-divider type of high-voltage probe employs a capacitor arrangement



(A) Capacitance divider.



(B) Compensated capacitance divider.

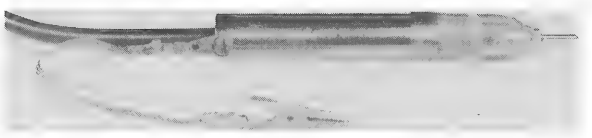
Fig. 6-1. Two types of high-voltage probes.

that provides an attenuation ratio of 1000-to-1. As seen in Fig. 6-1A, the output is taken across C2 and fed to the scope. Capacitor C1 has a high-voltage rating, such as 40,000 volts. The maximum input voltage to the scope in this example is 40 volts.

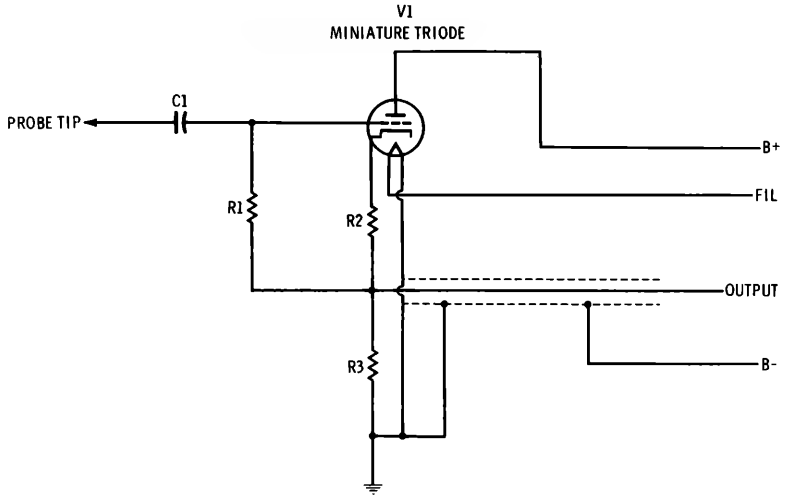
Although a capacitance-divider probe is simple and accurate at high operating frequencies, it is unsuitable for use in low-frequency tests. Since a scope has a certain value of input resistance (typically 1 megohm), this resistance will affect probe action and cause waveform distortion at low frequencies. For example, a typical capacitance-divider probe is unsatisfactory at frequencies less than 1 kHz. On the other hand, the high-frequency response of a capacitance-divider probe is limited only by the high-frequency response of the scope itself. When high-voltage waveforms are to be displayed at low frequencies, a more elaborate type of probe is required.

Next, let us consider the high-voltage probe depicted in Fig. 6-1B. This is a compensated capacitance-divider arrangement. That is, a resistive divider branch is included to provide compensated response at low frequencies. As in the previous example, an attenuation ratio of 100-to-1 is usually provided. Resistor R1 has a high-voltage rating, such as 40,000 volts. The

maximum input voltage to the scope is 40 volts, and the probe may be used from zero frequency (dc) up to the highest frequency at which the scope can operate. This type of probe is widely used in factories that produce high-voltage power equipment, such as transformers and circuit breakers.



(*A*) *Physical appearance.*



Courtesy Jackson Electric Instrument Co.

(*B*) *Schematic diagram.*

Fig. 6-2. Cathode-follower probe.

As noted previously, low-capacitance probes are widely used to minimize circuit loading. Another form of probe that provides high-impedance input is called the cathode-follower probe, as exemplified in Fig. 6-2. This type of probe is used extensively with lab scopes, and is occasionally used with service scopes. The chief advantage of a cathode-follower probe is the reduction in "trade-off" that is involved between

impedance step-up and signal step-down. For example, a low-capacitance probe provides a 10-to-1 step-up of input impedance in return for a 10-to-1 step-down of signal amplitude. On the other hand, a cathode-follower probe can provide a 10-to-1 step-up of input impedance in return for a 20-to-1 step-down of signal amplitude. In effect, the cathode-follower probe permits the scope to operate at five times greater sensitivity than otherwise.

Although an oscilloscope is ordinarily regarded as a voltmeter, a current probe can be employed to operate a scope as a current meter for display of current waveforms. Fig. 6-3

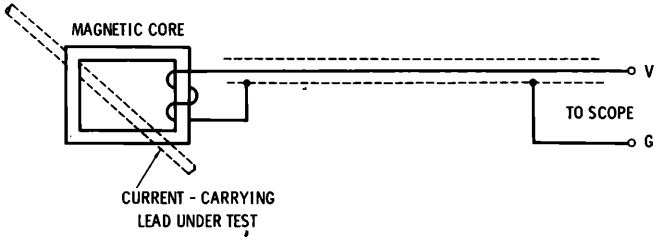


Fig. 6-3. Current-probe arrangement.

shows the basic plan for a current probe. It consists of a magnetic core, usually made of ferrite, and a winding into which the signal voltage is induced. The core is constructed with jaws that can be opened. To make a current-waveform test, the probe jaws are opened and the current-carrying lead is inserted, as depicted in the diagram. Thereby, the lead acts as a one-turn primary when the probe jaws are closed. The voltage waveform that is induced in the probe coil, or secondary, is the same as the current waveform in the lead under test. Thereby, the current waveform is effectively displayed on the scope screen.

In practice, the basic arrangement shown in Fig. 6-3 is elaborated somewhat. Since the response of the simple current probe tends to fall off at low frequencies, RC frequency-compensation networks are used to extend the useful low-frequency response; typically down to 60 Hz. Moreover, small currents, such as one milliampere peak-to-peak, induce only a small voltage in the probe coil. Therefore, a solid-state probe amplifier is generally included so that small current values will produce adequate deflection on the scope screen. The probe

amplifier includes a gain control, so that the current probe can be calibrated. A sensitivity of one millivolt output per milliampere of current is typical of conventional current probes.

Integrator probes are used with lab scopes in certain applications. Basically, an integrator probe can be compared with the coaxial cable and isolating-resistor arrangement used with service scopes in sweep-alignment procedures. However, an integrator probe is designed as a precision device that provides exact integration of the applied waveform. Fig. 6-4 shows the arrangement of an integrator probe. It consists of a series resistor followed by an operational amplifier. An operational amplifier is essentially a solid-state class-A amplifier with a negative-feedback loop that provides a specified mathematic operation on the signal. That is, an operational amplifier is a signal processor. An integrator probe employs a feedback capacitor C from output to input. The input impedance of the probe is high.

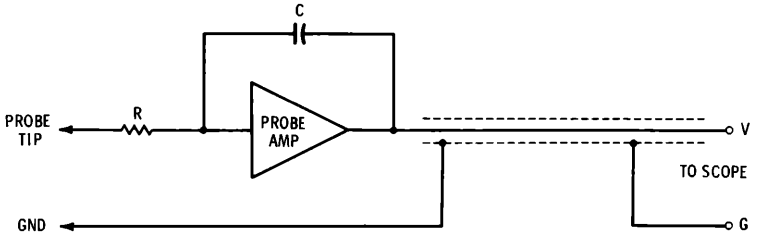


Fig. 6-4. Integrator-probe arrangement.

A *logarithmic* probe, or log adapter, is comparable to an integrator probe, except that the former is an amplitude processor instead of a frequency processor. A logarithmic probe employs an operational amplifier with a feedback network that provides an output which is proportional to the logarithm of the input signal amplitude. This is a lab probe and is not used in service procedures. The action of a log probe can be summarized by observing that the input signal is measured in volts, whereas the probe output is measured in decibels. Decibel units are extensively used in engineering work. One of the advantages is that decibel units are proportional to eye and ear response.

ELECTRONIC SWITCHES

Electronic switches are used to provide dual-beam displays with conventional oscilloscopes. A typical electronic switch is illustrated in Fig. 6-5. The plan of an electronic switch is seen in Fig. 6-6. It consists essentially of a pair of switching circuits composed of S1 and S2. When S1 opens, S2 closes, and vice versa. In turn, signal inputs 1 and 2 are alternately applied to the vertical-input terminals of the scope. This is a basic example of a signal-sampling or time-sharing display

Courtesy Dumont Laboratories, Div. Fairchild Camera & Instrument Corp.

Fig. 6-5. Electronic switch.

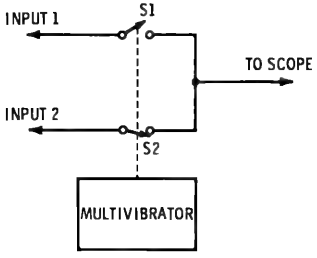


Fig. 6-6. Electronic switch plan.

method. Switches S1 and S2 are opened and closed by the square-wave output from a multivibrator. The switching devices are usually transistors that are biased alternately into conduction and into cutoff. Thus, the output from the switch arrangement consists of a square wave with one signal superimposed along the top and the other signal superimposed along the bottom.

TIME-MARK GENERATORS

Maintenance procedures for triggered-sweep scopes involve periodic check of the sweep-time calibration. In case observable drift has occurred, the horizontal sweep rates are adjusted as required. To check sweep-time calibration, a very accurate frequency source is necessary. Time-mark generators particularly suited to operating convenience are available for this purpose. A time-mark generator is a crystal-controlled pulse oscillator that provides pulse rates corresponding to sweep-time control rates. The calibration of a time base is often checked by applying the output from the time-mark generator to the intensity-modulation terminal of the scope. In turn, blanked intervals appear on the trace, as illustrated in Fig. 6-7.

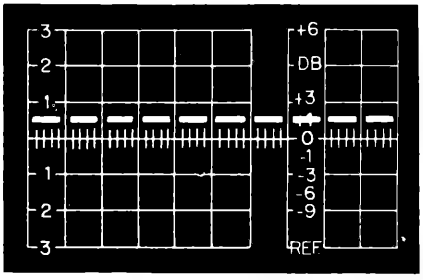
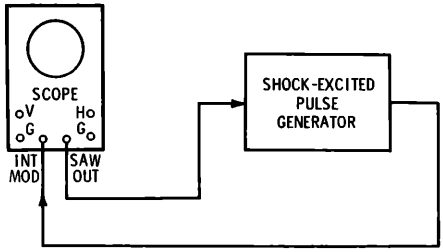


Fig. 6-7. Time-mark pattern on oscilloscope screen.

Intensity modulation of the crt beam occurs when a waveform voltage is applied to the first grid in the crt. If a negative pulse of sufficient amplitude is applied, the beam will be cut off for the duration of the pulse. This is the method that is employed to produce the pattern of Fig. 6-7. Note in passing that a time-mark generator can be used to provide a calibrated time base for a conventional scope. That is, if a test setup such as that depicted in Fig. 6-8 is used, the blanked intervals mark

time along the waveform display. In this application, a shock-excited pulse generator is required, and the generator must be synchronized by the horizontal-deflection voltage to prevent the time marks from "running" in the pattern.



(*A*) *Equipment connections.*

(*B*) *Oscilloscope pattern with time marks.*

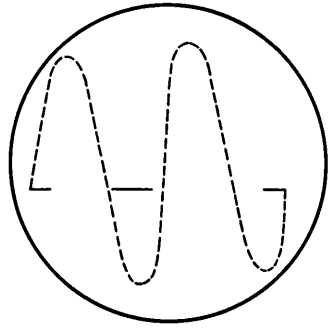


Fig. 6-8. Time-base calibration for a conventional scope.

A shock-excited pulse generator consists of a quartz-crystal arrangement that "rings" when the sawtooth-deflection voltage from the scope changes amplitude suddenly during retrace. A damped sine-wave with a very precise frequency is thereby generated. This waveform is passed through a limiter to obtain an output of uniform amplitude. The limiter output, in turn, is passed through a wave-shaping circuit which produces a series of sharp pulses. These pulses comprise the time-mark signal that is applied to the intensity-modulation channel of the scope. Since a new pulse train is initiated at the start of each sweep, the time marks remain stationary on the screen pattern, regardless of the vertical-input signal frequency.

CRT LIGHT FILTERS

Crt light filters are used to improve pattern contrasts under conditions of ambient illumination. Most service scopes utilize green transmission filters. This type of filter is essentially transparent with respect to the green crt trace, but makes the white screen surface appear almost black. In turn, the effective contrast of the display is considerably increased. Lab scopes often utilize green filters, but may also use blue, amber, or smoke-gray filters in special situations. Filters are available in various shapes and sizes, as exemplified in Fig. 6-9. Mesh filters provide optimum contrast under high ambient illumination. A mesh filter is a black fine-mesh screen that eliminates reflections from ambient light. Although the apparent bright-

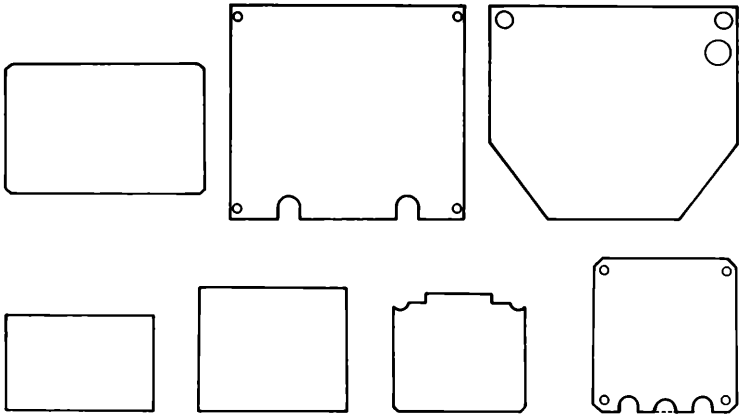


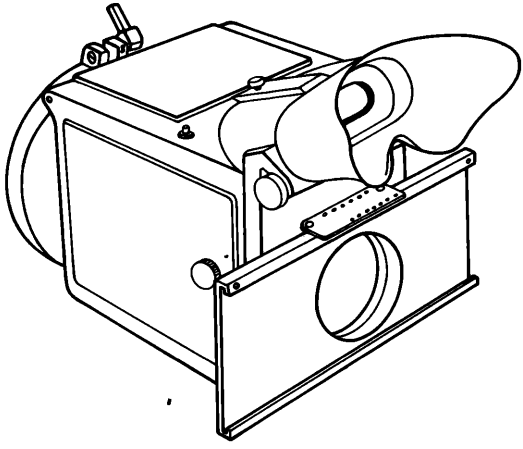
Fig. 6-9. Crt light filters.

ness of the screen pattern is substantially reduced, the high contrast which is provided facilitates pattern viewing.

OSCILLOSCOPE CAMERAS

Oscilloscope cameras, as shown in Fig. 6-10, are designed for convenience, ruggedness, and versatility. This type of camera provides for direct recording and oblique viewing while recording. Direct viewing can be done, if a ground-glass slide is utilized before the camera is loaded with film. The camera is mounted on the oscilloscope by means of a clamp

ring. An interchangeable lens system is provided. One lens is used to obtain full-size images, another permits two images to be recorded on one frame, and another provides for the use of 35-millimeter film. Polaroid cartridges are often used because the print can be inspected very shortly after exposure.



Courtesy Dumont Laboratories, Div. Fairchild Camera & Instrument Corp.

Fig. 6-10. Oscilloscope camera with viewing hood.

An ultraviolet light option is available with some types of oscilloscope cameras. This device permits visible photos to be made of waveform details or high-speed transients that are too dim for conventional cameras, even when used with high-speed lenses. Introduction of ultraviolet light produces a two-fold increase in effective film speed. It has an effect similar to "post-fogging" of the film at the same time that the picture is taken. Ordinarily, a very faint trace will not expose the film sufficiently to bring the density level into the gray region. However, ultraviolet light moves the exposure level above the brightness threshold level, and the slight increase in exposure caused by the trace then becomes visible.

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